PD21

SPACE STATION SYSTEMS TECHNOLOGY STUDY

Final Report

VOLUME I

EXECUTIVE SUMMARY

D180-27935-1

Conducted for NASA Marshall Space Flight Center

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Boeing Aerospace Company

Spectra Research Systems

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FOREWORD

The Space Station Systems Technology Study (Contract NAS8-34893) was initiated in June 1983 and to be completed in April 1984. The study was conducted for the National Aeronautics and Space Administration, Marshall Space Flight Center, by the Boeing Aerospace Company with Spectra Research Systems as a subcontractor. The study final report is documented in three volumes.

D180-27935-1	Vol. I	Executive Summary
D180-27935-2	Vol. II	Trade Study and Technology Selection Technical Report
D180-27935-3	Vol. III	Technology Advancement Program Plan

Mr. Robert F. Nixon was the Contracting Officer's Representative and Study Technical Manager for the Marshall Space Flight Center. Dr. Richard L. Olson was the Boeing study manager with Mr. Paul Meyer as the technical leader and Mr. Rodney Bradford managed the Spectra Research Systems effort. A listing of the key study team members follows.

KEY TEAM MEMBERS

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LIST OF ACRONYMS AND ABBREVIATIONS

APSTS	Advanced Platform Systems Technology Study
BAC	Boeing Aerospace Company
BIT	Built In Test
CADMS	Communications and Data Management Station
CAE	Computer Aided Engineering
CAMPS	Construction and Material Processing Station
CCD	Change Coupled Device
Cg	Center of gravity
CMG	Control Moment Gyros
$C0_2$	Carbon dioxide
CPU	Central Processor Unit
CRT	Cathod Ray Tube
dc/ac	direct current/alternating current
deg/sec	degrees per second
DMS	Data Management System
EASY	
EVA	Extra Vehicular Activity
ft	feet
FY	Fiscal year
HR	Hour
H_20	water
IAC	
I.D.	Inside diameter
I/O	Input-output
JSC	Johnson Space Center

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

KG	Kilograms
kW	Kilowatts
LAN	Local Area Network
lb	pound
LED	Light Emitting Diode
LISP	List processor
LOARS	Land, Ocean, and Atmospheric Research Station
MBPS	Million bits per second
MHZ	Megahertz
MIPS	Million iterations per second
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NASTRAN	
NIU	Network Interface Unit
N-M-Sec	Newton-meter-seconds (a measure of force)
NOS	Network Operating System
ns	nanoseconds (10^{-9} seconds)
O.D.	outside diameter
ORACLS	Optimum regulator and control of linear systems
OTV	Orbital Transfer Vehicle
PIN	Positive intrinsic negative
PSI	Pounds per square inch
PSIA	Pounds per square inch absolute
PSID	Pounds per square inch differential
R&D	Research and development
RCA-PRICE	Radio Corporation of America - Price Modeling program
RFP	Request for Proposal
R1	Expert system used to configure VAX installations

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

R/T	Receiver - Transmitter
RTOP	Research Technology Objectives and Plans
sec	second
SRS	Spectra Research Systems
TCC	Trace Contamination Control
TDMA	Time division multiple access
TDRSS	Tracking and Data Relay Satellite System
VAX	Virtual Address Extension
VCD	Vapor compression distillation
VHSIC	Very High Speed Integrating Circuit
WQM	Water Quality Monitor

1.0 INTRODUCTION

This is the Executive Summary which is volume I of the final report on the Space Station Systems Technology Study conducted for the Marshall Space Flight Center (MSFC) by the Boeing Aerospace Company (BAC) and Spectra Research Systems (SRS). The overall study objective was to identify, quantify, and justify the advancement of high-leverage technologies for application to both the early and more advance space station. Research plans were developed for each of the selected high-leverage technologies. The objective was fulfilled through a systematic approach tailored to each of the technology areas studied.

The current Space Station Systems Technology Study was an outgrowth of the Advanced Platform Systems Technology Study (APSTS) which was completed in April 1983 for MSFC by the Boeing/SRS team. The first study proceeded from the identification of 106 technology topics to the selection of five for detail trade studies. During the Advanced Platform Systems Technology Study, the technical issues and options were evaluated through detailed trade processes. Individual consideration was given to costs and benefits for the technologies identified for advancement, and advancement plans were developed. An approach similar to this was used in the current study with emphasis on system definition in four specific technology areas.

The four study areas addressed in the Space Station Systems Technology Study are: (1) Attitude Control, (2) Data Management, (3) Long-Life Thermal Management, and (4) Automated Housekeeping Integration. These four areas are extensions of areas identified during the APSTS and were conducted to facilitate a more in-depth understanding of the technology issues. While high-leverage technology identification was a study goal, different study approaches were used for each study area. The attitude control study utilized a specific representative configuration and determined by simulation the applicability of a low-bandwidth control system for space station use. The data management task concentrated on the architecture characterization into structural blocks and systems to facilitate simulation planning. The thermal study focused on characterizing a two-phase heat transport systems within the long life requirement constraints. The automated housekeeping task was structured to characterize the functions of an integrated controller for an overall management system. Each of these approaches produced useful advancements in the understanding of technology issues and development needs. The summary discussions are presented in the following sections.

The overall study was divided into four tasks. During task 1 the design concepts in each of the four study areas were refined. The concepts were used to annunciate specific technology options upon which comparative studies were conducted. Candidate high-leverage advancement technologies were then selected from the options. The cost, benefits, schedules, and life cycle costs for the options were evaluated in task 2. Selection of the technology advancement items was made during this latter task. Technology advancement plans were prepared for each of the selected items in task 3. All study documentation was prepared in task 4. The overall study plan flow diagram is shown in figure 1.0-1.

This volume presents a summary of the work performed to select these high leverage items. The total final report is made up of this volume, Volume II: Trade Study and Technical Selection Technical Report, and Volume III: Technology Advancement Program Plan. More detailed discussion of the trades conducted and the technology advancement plans are given in volumes II and III respectively.

1.1 TECHNOLOGY SELECTIONS AND RATIONALE

Seven potential technology advancement items were identified during this study. These items were analyzed and evaluated in task 2, considering technical as well as cost benefits and schedule criteria. Study plans were prepared for each of the selected high leverage items. These selected items are:

1. Data Management System Simulation Package.
2. Data Management Network Interface Unit.
3. Data Management Network Operating System.
4. Two Phase Thermal - Long Life Pumps.
5. Two Phase Thermal - Heat Exchanger.
6. Two Phase Thermal - Two Phase Water System.
7. Integrating Controller for Space Station Autonomy using Expert Systems.

The following sections summarize the rationale associated with selections made in each of the four study areas.

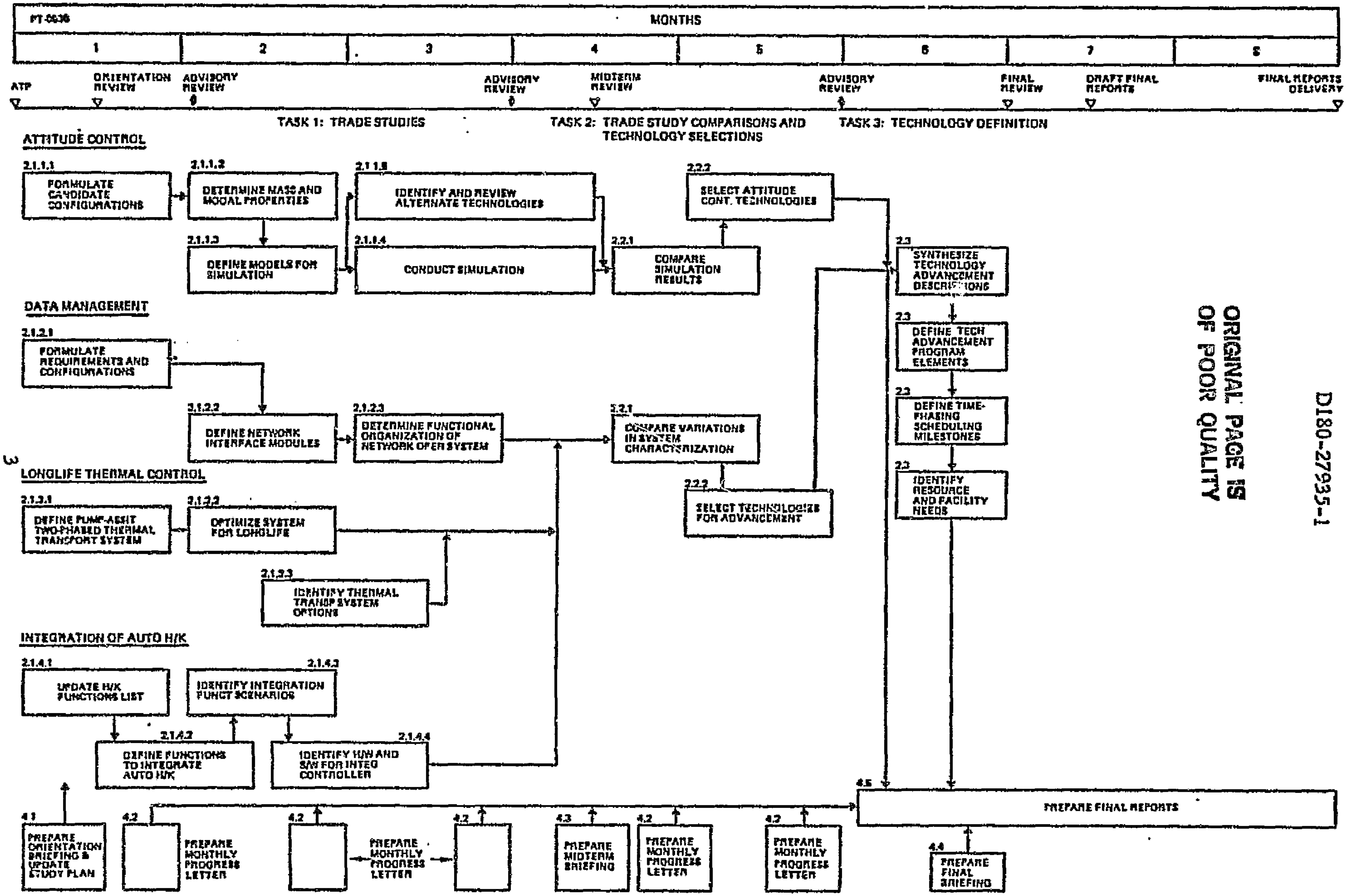

Figure 1.0-1 Study Plan Flow Diagram

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1.1.1 Attitude Control Rationale

The objective of the attitude control study was to investigate a control system concept thru simulation modelling to assess whether a core-mounted reactive controller could provide satisfactory attitude control of a typical space station. The simulations were run, and the results indicate that a core-mounted controller that reacts to disturbances fed back thru the structure is stable. The simulation results did expose a potential problem area due to very lightly damped oscillations at the astromasts in response to modelled one shot disturbances. These oscillations appear to be of low amplitude and therefore may not be disruptive to the space station. Modelling of the effect of cumulative disturbances is indicated for future studies.

The reason this simulation approach was taken is that speculation has been extensive on how difficult the flexible dynamics of the station would be to control. This simulation study is a start toward a better understanding of that problem, and a better understanding of where technology advancements are really needed in the attitude control area.

1.1.2 Data Management Rationale

The rationale for the technology selections in the data management area is that the system will be complex and highly interactive with other systems and with missions of the space station. An early simulation is therefore required of the data management system allowing synthesis of the local area network (LAN) and sizing of data management system components. The simulation package definition, in the presence of all the undefined complexity of the space station at this time, is a technology advancement effort that needs to be started.

The Network Interface Unit and Network Operating System advancements are the hardware and software areas needed to support the development of a local area network for the space station. Within these two areas, several specific items are recommended for advancement and are listed on figure 2.3-9 of this volume. Examinations of the study configurations and concepts did not reveal any specific technology that is likely to be a show stopper if not advanced. However, the general complexity of the system and the data management interfaces indicate that early structuring thru simulation is essential.

The cost benefits analysis of the APSTS was not changed by the conclusions of this study. The reduction in system development and operating costs thru use of a well defined local area data management network remains as an impressive eight dollar saving of system integration costs for every dollar spent in establishing an early structuring of the data management system.

1.1.3 Long Lifetime Thermal Rationale

The rationale for the technology selections in this area is based on the results of an analysis of the weight, size, and complexity of two-phased heat transport system concepts as compared with pumped liquid concepts. The first result of the study is that the two-phased concepts will be several thousand pounds lighter than the single phase liquid systems. The second result is that use of a two-phased loop for the interior cabin heat transport would improve the weight advantage of the two-phased system by approximately 1000 additional pounds. This internal two-phased loop would also provide design flexibility to support space station evolution. For these reasons, the development of a two-phased (non toxic) water loop for heat transport within the space station pressurized cabins is selected as a primary technology for advancement.

Further technology advancement effort to improve the life of pumps operating in space is based on existing studies that indicate that current centrifugal pumps are unlikely to operate continuously for the 10 years associated with the space station. Heat exchanger technology advancement is also indicated especially when two-phased systems are used both for the pressurized module heat transport and the main heat transport system on the space station.

The cost benefits analysis for these technology advancements is detailed in section 4.3.9 of volume II. In summary, the benefits are based on transportation cost savings due to weight reduction, radiator assembly cost savings due to smaller area, and system development cost savings due to reduced complexity (RCA-PRICE modelling was used here). The costs were the estimated technology advancement costs. The result was that eight dollars in quantified benefits could be achieved for every three dollars spent in advancing the technologies in this area.

1.1.4 Integration of Automated Housekeeping Rationale

The concept development group for the space station task force has established an autonomy/automation philosophy for the space station (see table 2.5-1). This philosophy is in agreement with the needs of a space station to provide a facility for a wide range of missions without encumbering the crew (or mission controllers) with excessive hours for station upkeep. This philosophy is also in agreement with the needs for efficient and balanced operation of the space station complex systems over extended lifetimes with limited consumable and power resources. The rationale for autonomous systems to provide housekeeping of the space station is that they are completely consistent with the needs of a meaningful long life and evolutionary space station concept.

The rationale for the development of an integrating controller is that the controller is necessary for space station autonomy because it provides overall decision-making functions to replace those that would otherwise have to be provided by human mission controllers or astronauts. The results of developing the integrating controller may also drive out needs for advancements in space qualified data processing equipment, sensors, actuators, and devices for interacting with the crew. If advancements in these areas are needed, the development lead times may be long so those needs should be identified by starting and advancement program for the integrating controller as soon as possible.

The cost benefits assessment of this study resulted in some modification of the conclusions of the Advanced Platform Study completed in April of 1983. The cost modification was based on higher costs due to higher labor rates and a more detailed understanding of the functions of the concept. The benefits were modified due to a consideration of phased application of the technology to the space station over a ten year period. The result was that the cost versus benefit ratio changed from one to ten to four to ten. This still provides an impressive return on the advancement dollars spent and does not consider the significant unquantifiable benefits of the integrating controller.

2.0 TECHNICAL SUMMARIES

This section summarizes the results of the trade study and technology advancement planning efforts conducted for the Space Station Systems Technology Study.

2.1 INTRODUCTION

The trade study effort conducted on Space Station Systems Technology Study characterized system concepts in order to define cost versus benefits for data management architecture, long-life thermal management, and integration of automated housekeeping. The attitude control topic selected for study focused on characterizing the space station attitude control problem through simulation of non interacting control system responses. The first three topics, mentioned above, focused on specific technology items that require advancement in order to support a 1990 initial launch of an early space station, while the attitude control study was an exploration of the capability of a conventional controller.

The characterization studies were structured to start with the issues identified in the Advanced Platform System Technology Study completed in April of 1983. Investigation of these issues motivated consideration of a more detailed characterization of the four topics that were then covered in this current study. A definition of concepts based on space station needs and constraints was developed for each of these areas as an initial step in the current study. These concepts were based on requirements that were derived from space station related documentation or from requirements known to exist for similar missions. The next step was to develop the characterizations to identify options within the trade topics. Based on life cycle costs and benefits the options were then evaluated and technologies necessary to support the more promising options were identified.

Cost and schedule factors related to advancing the technologies recommended in the data management, long lifetime thermal management and integration of automated housekeeping areas are also summarized in this section.

The four study topics are presented in this final report in the order that was established by the RFP. That order is attitude control first, then data management architecture, long-life thermal and lastly, integration of automated housekeeping. A summary of the

study approaches and results of the four topics is presented in this volume. Detail trade study technical information is in volume II, and detailed advancement planning information is provided in volume III.

2.2 ATTITUDE CONTROL

The objective of the attitude control study was to examine the technologies required for solving the control-structure interaction problem in space station design. The approach was to determine through analysis and simulation the degree to which noninteracting low-band controller technology is applicable to attitude regulation of a space station with large flexible solar arrays. Primary emphasis was given to identifying the limitations of low-band controller technology for flexible space station applications. Passive and active control technologies were to be reviewed as potential improvements to the damping provided by a low-band controller in the event that attitude stability and performance was unacceptable.

In this study all the available attitude information, including flexible effects as measured by an ideal sensor package mounted on the core station, is passed to ideal control moment gyros (CMG) actuators that attempt to control the attitude about the center of mass. The low band controller will therefore attempt to regulate attitude in the presence of induced disturbance torques due to flexibility without actively controlling the motion of the flexible elements. This simulation study demonstrated that a core-mounted linear ideal controller is stable in the presence of flexibility and will provide significant damping of most of the major structural modes. Some of the modes, however, cannot be controlled with a core mounted controller. The important issues are the amplitude to which those modes are excited and the implications of sustained vibration of the associated structural members.

Tight-pointing accuracy requirements could produce associated requirements for increased control system bandwidth. As controller bandwidth increases, many structural modes will be included within the controller passband. Active stabilization of these modes without sacrificing pointing accuracy is another major issue. Adapting to variations in mode shapes and frequencies caused by space station configuration changes is also a major issue.

2.2.1 Technical Approach

The technical approach is formulated in terms of five main tasks. These tasks are identified in the discussion to follow.

The first task in the process was to select the configuration for the space station technology study. This was derived from the limited class premise with adherence to the NASA governing assumption which is "a space station as a permanently inhabited facility engaged in productive work and delivered to low earth orbit in stages the dimensions of which are consistent with the shuttle cargo bay."

The second task was to develop a schematic architecture consistent with the functional attributes and incorporating various strategies for growth leading to a 12-man configuration representative of shuttle deliverable hardware.

The attitude control study considered four operational stages that incorporate two phases of assembly, with and without the orbiter docked. The two phases of assembly will include the initial habitable stage and the all-up fully operational stage.

A pictorial view of the study configuration is shown in fig. 2.2-1. A representative build up sequence is shown in fig. 2.2-2 along with the stages selected for analysis.

Mass balance was a principal design goal in order to ensure that CMG controllers will enable attitude stabilization with minimal expenditure of energy for momentum management. Dynamic balance is achieved by center pivoting the solar panels. This configuration eliminates dynamic products of inertia that arise as the panels are rotated to track the sun line. The center mounted solar panels also increase the lowest frequency structural mode by a factor of two due to halving the length of the solar panel deployment mast.

The third task was to develop a finite element model of the station and the resulting mass and stiffness distribution of the structure into NASTRAN. The output modal data from NASTRAN established the normal mode shapes and natural frequencies of vibration for the simulation.

The fourth task was to develop a system of analysis programs for control and structure interaction analysis and simulation, and these are shown in fig. 2.2-3. Finally, the analysis of attitude control system stability was performed by arguments based on the theory of positivity of operators. The basic stability theory was verified by frequency response methods and time response from simulation of the closed loop system. The performance of the closed loop system was determined from time response data. System performance includes the motions of the central core and the flexible elements. Stresses at the root of the solar array boom and astromast were derived from time response data.

2.2.2 Technical Discussion

The simulated response of the structure to the test disturbance represented by an impulse doublet was computed for both open loop and closed loop cases (see figure 2.2-4). The block diagram for the closed loop system representing an attitude regulator is shown in figure 2.2-5. The nodal structure indicating the nodes used to extract measurement data is shown in figure 2.2-6. Motion of the core structure relative to an inertial frame was extracted from the rotational state of the variables ϕ, θ, ψ (roll, pitch, and yaw, about x, y, z) of node 100. Measurements of flexible element motion relative to node 100 are specified as follows. These rotational measurements indicate the flex and twist of the solar panel boom and the astromast structure,

M_{B_x} = Flex of panel boom ($\phi_{100-105}$)
M_{B_y} = Twist of panel boom ($\theta_{100-105}$)
M_{B_z} = Flex of panel boom ($\psi_{100-105}$)
M_{A_x} = Twist of the astomast ($\phi_{100-323}$)
M_{A_y} = Flex of the astomast ($\theta_{105-323}$)

The quantities ε_ϕ, ε_θ, ε_ψ represent the contribution of the flexible modes to the total attitude response. For example $\theta = \theta_f + \varepsilon_\theta$ is the total rotational response of node 100 about the pitch axis and θ_f is the component due to the free - free motion only. It is noted that quantities M_{B_x}, M_{B_z}, and M_{A_y} represent the mode slopes at the end of the associated flexible members. All response quantities are in arc-sec.

2.2.2.1 Control System Responses

Examples of the simulated response of the attitude regulator to the test disturbance are shown in figures 2.2-7 thru 2.2-9. The system bandwidths chosen for presentation are .05 Hz for configuration 1 and .25 Hz for configuration 2. The controller was a simple

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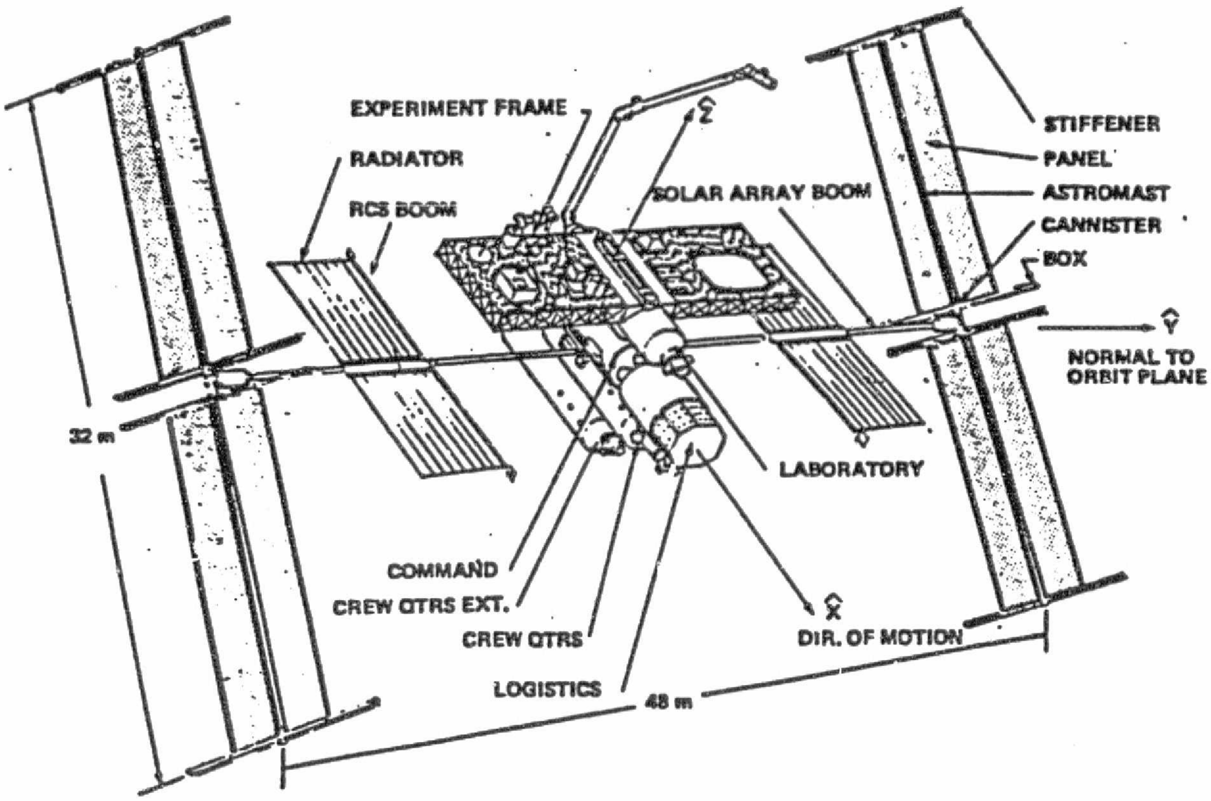

Figure 2.2-1. Space Station Balanced Array Concept with Astromast Solar Array Deployment

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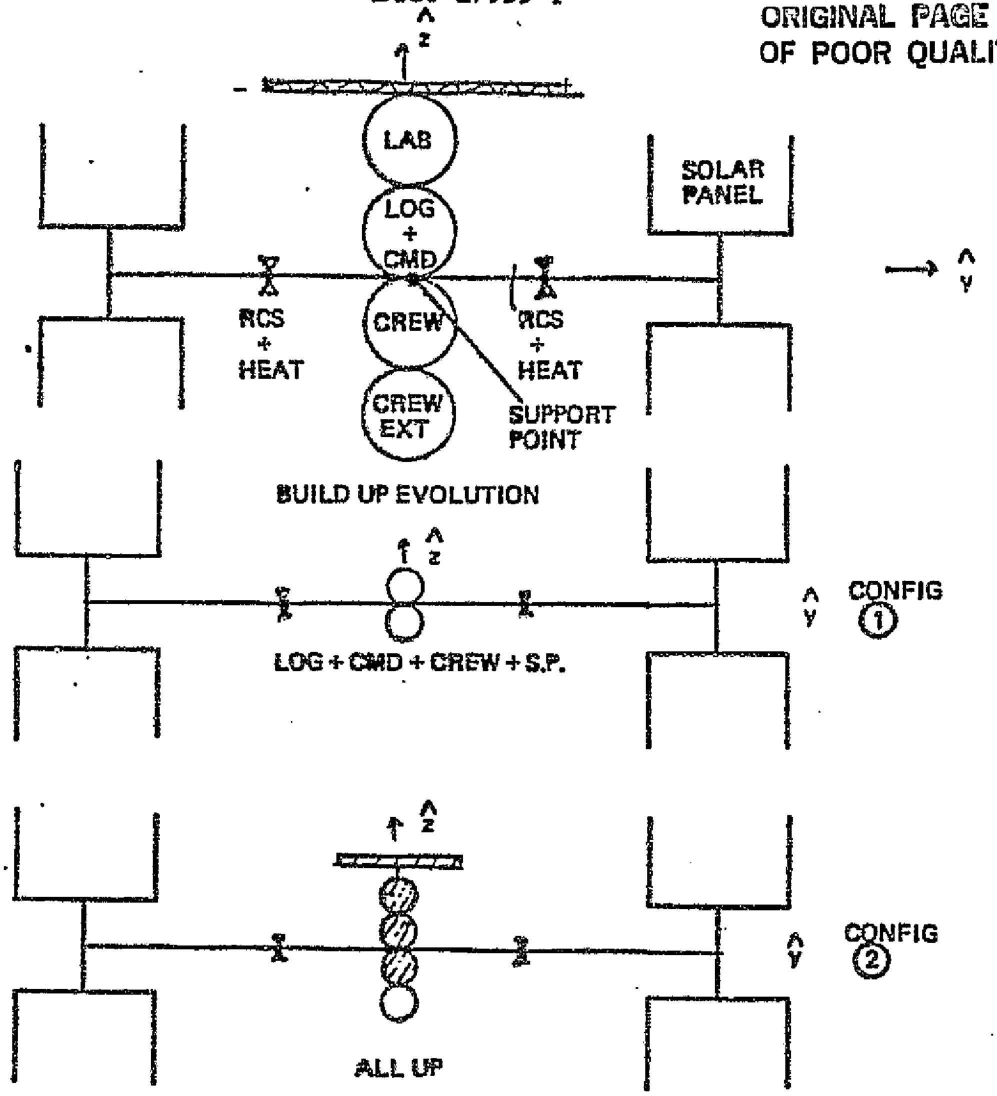


Figure 2.2-2. Buildup Sequence Defining Configuration for Control/Structural Analysis

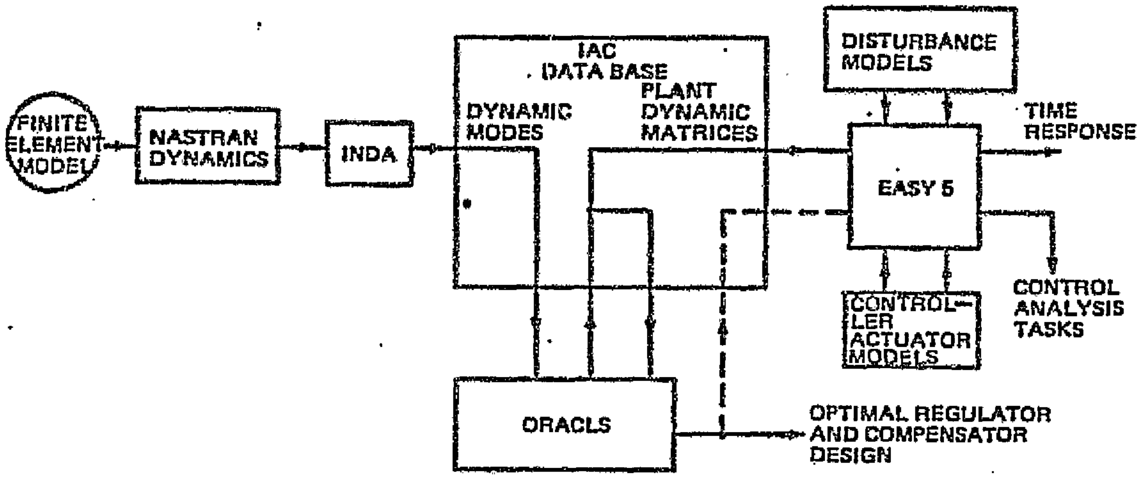
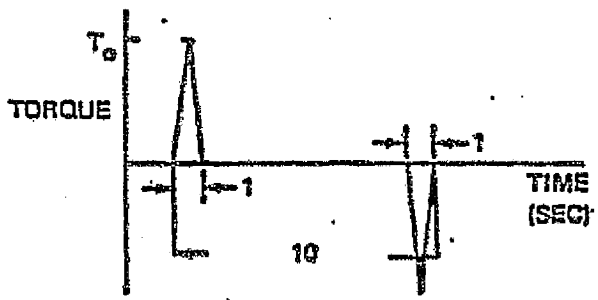
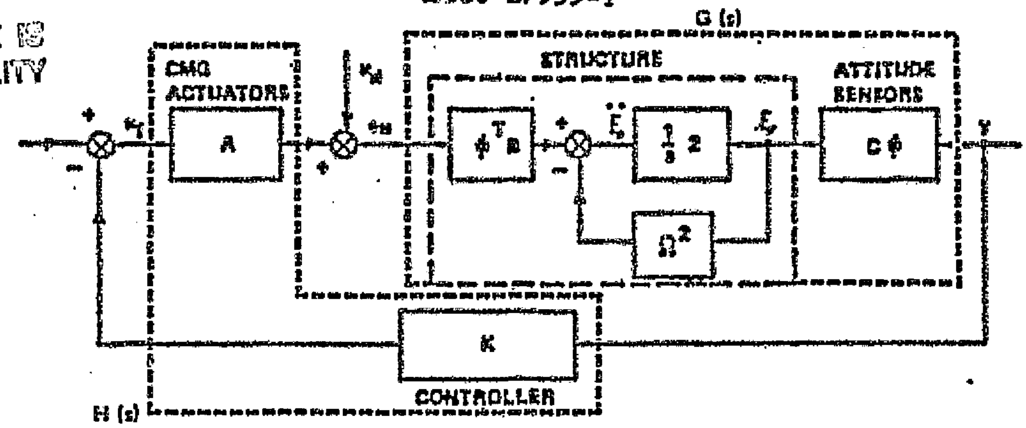


Figure 2.2-3. Software Architecture Technical Approach for Dynamic Simulation and Analysis



- ASTRONAUT PUSH OFF AND FREE FLIGHT
  - CREW MEMBER MASS = 100 KG
  - FREE FLIGHT VELOCITY = .40 M/S
  - PATH CG OFFSET = 01 m 10 m
  - NET DISTURBANCE MOMENTUM H_o = 400 N-M-SEC

Figure 2.2-4. Disturbance Model for Crew Activity



VECTORS			DISTRIBUTION MATRICES		
u	=	TOTAL TORQUE	A	=	CMG TORQUE
ξ	=	MODAL COORDINATE	B	=	CONTROL INPUT
y	=	MEASUREMENT	C	=	MEASUREMENT
f	=	FEEDBACK TORQUE COMMAND	ϕ	=	MODAL STATE (EIGEN VALVE)
			Ω^2	=	EIGENVALUE DIAGONAL
			K	=	FEEDBACK CONTROL

Figure 2.2-5. Generic Block Diagram of an Attitude Regulator for a Flexible Structure

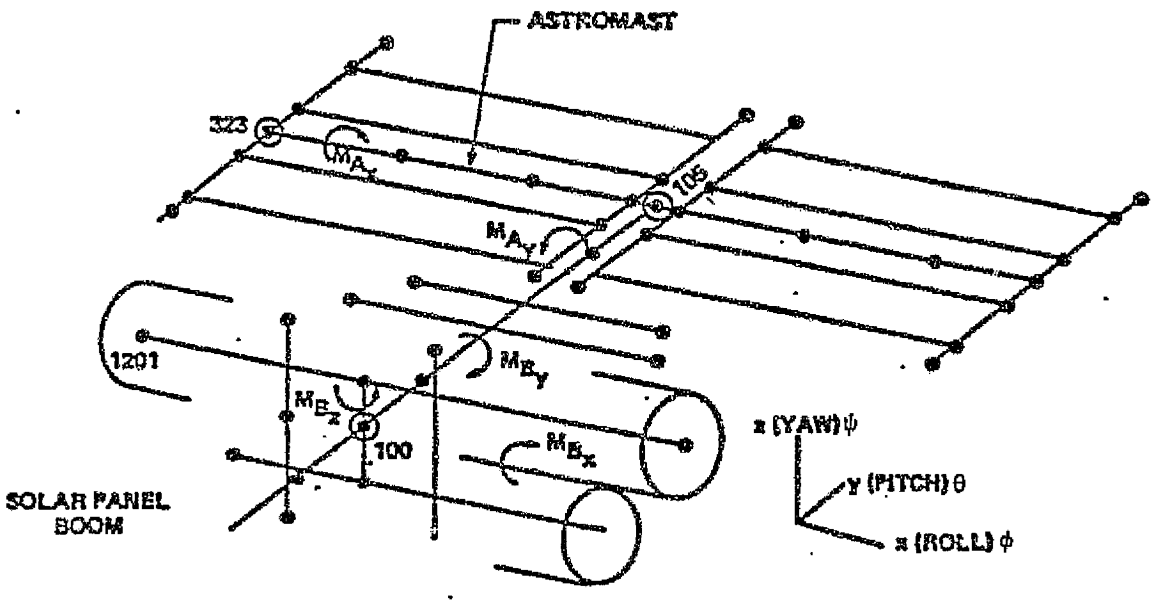


Figure 2.2-6. Measurements of Flexible Elements for Reference in Time Histories

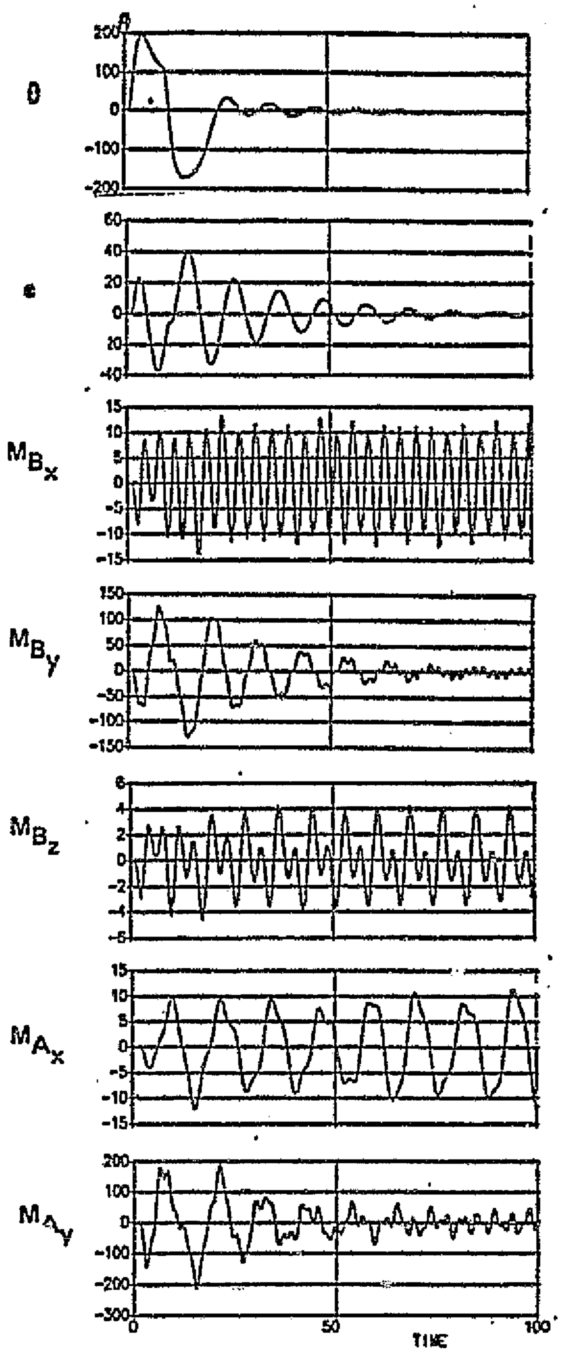


Figure 2.2-7. Closed Loop Response (arc-secs) to 1000 N-M-Sec Impulse Doublet in Pitch for Configuration 1

System Bandwidth = .05 Hz

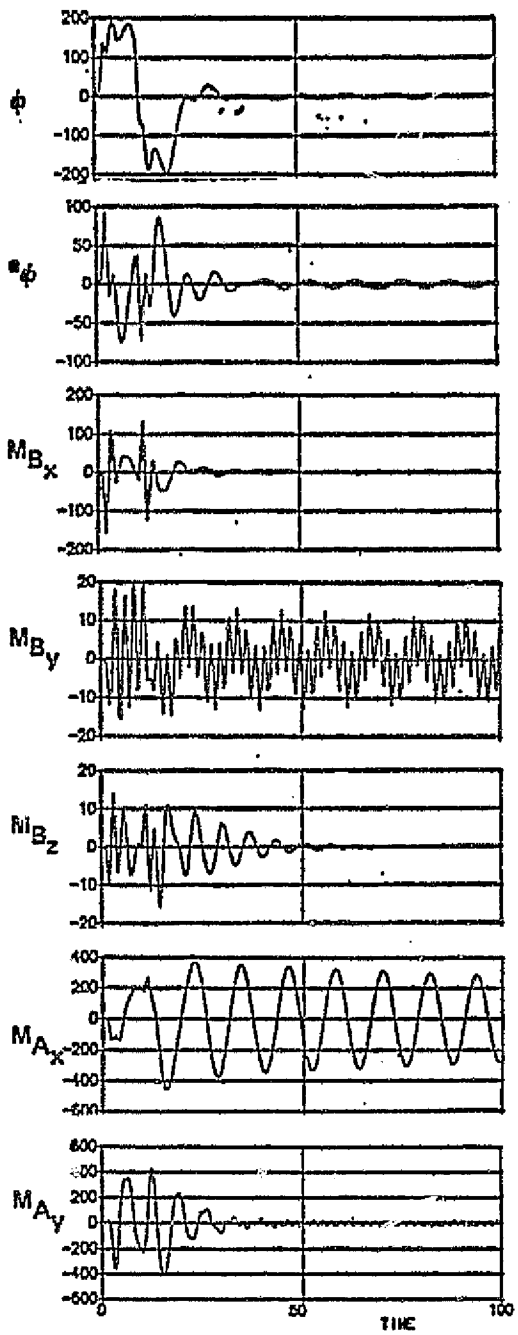


Figure 2.2-8. Closed Loop Response (arc-secs) to 1000 N-M-Sec Impulse Doublet in Roll for Configuration 1

System Bandwidth = .05 Hz

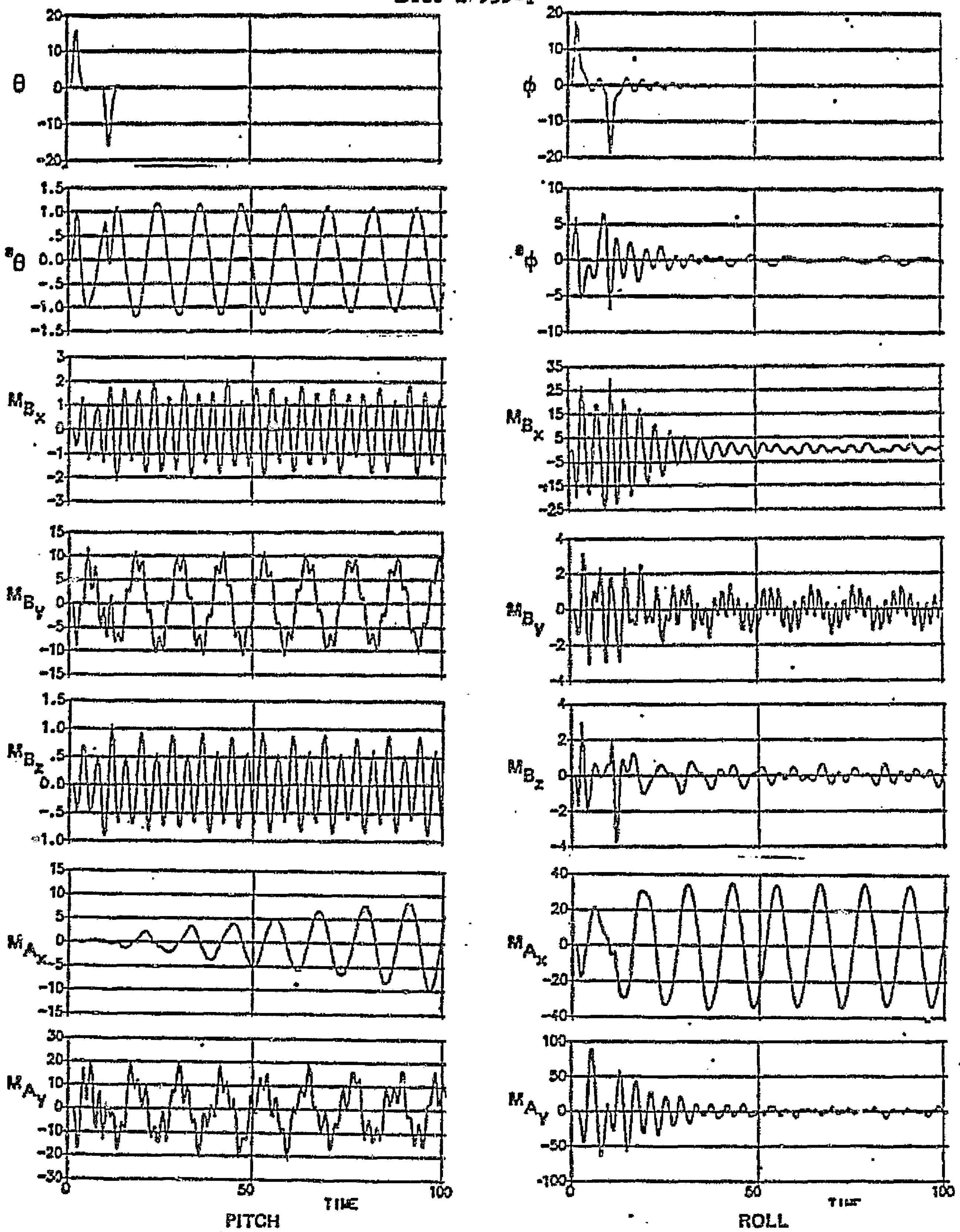


Figure 2.2-9. Closed Loop Response (arc-secs) to 1000 N-M-Sec Impulse Doublet in Pitch and Roll for Configuration 2

System Bandwidth = .25 Hz

proportional plus derivative feedback of free - free mode attitude measured at node 100 (fig. 2.2-6). The time responses indicate that regulated free - free mode attitude is both stable (in accordance with theoretical predictions) and controllable. The controllability of the structure is not surprising because the impulse energy analysis has clearly indicated that controllable normal modes contain motions of all structural elements with the exception of the astomast twist. The time responses support this claim and would indicate that torsional vibrations of the astomast are not controllable with the controllers and sensors mounted on the rigid core as expected.

It is noted that the rate of suppression of vibration (damping) in the structural elements appears to be independent of vehicle inertia for fixed free - free mode control bandwidth. However, the magnitude of the vibration is, of course, inversly proportional to vehicle inertia as expected. The damping of structural vibrations for a given vehicle inertia decreases with increasing free-free mode control bandwidth. This is due to the fact that with increasing bandwidth the closed loop modal poles approach the open loop modal zeros, which are virtually undamped. The result is that the residual in the response due to a given modal pole is reduced but so is the closed loop damping on that pole.

The response of the structure to a typical orbiter docking from impact loading at body station 1201 is shown in fig. 2.2-10. It is assumed that the orbiter has an initial rotational rate at docking about its c.g. of $_{o}$= .2 deg/sec with a linear velocity of $_{o}$= .15 m/sec as shown in figure 2.2-11. Assuming the centerline of shock is 1 meter from the station c.g. and further assuming that the collision is perfectly elastic, the resulting impact will impart approximately 2500 N-sec to the station.

2.2.3 Summary of Results

The important control and structure interaction issues for a representative space station configuration have been addressed. Specifically, the stability and performance of the station with a core-mounted linear controller has been investigated. The inertias are of order 10^6 with solar panel size of 1100 m^2, which is consistent with a 75 kW power requirement. The following statements summarize the results of the study.

1. Analysis has shown and the simulation has verified that the raft configuration is stable and controllable when ideal sensors and CMG actuators are colocated.

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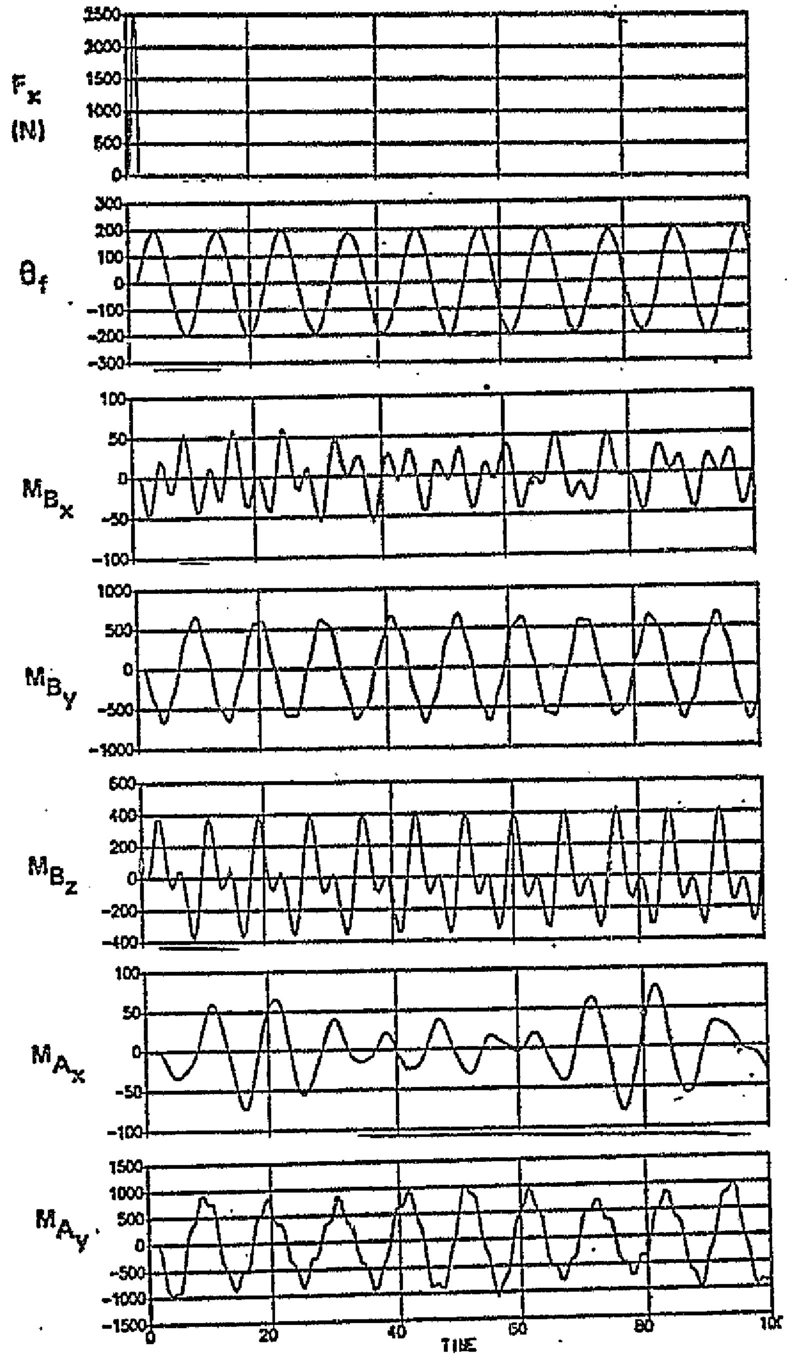

Figure 2.2-10. Impulse Response (arc-sec) of Configuration 1 to Docking Load of 2500 Newtons at Body Station 1201 (Force Along X-Axis)

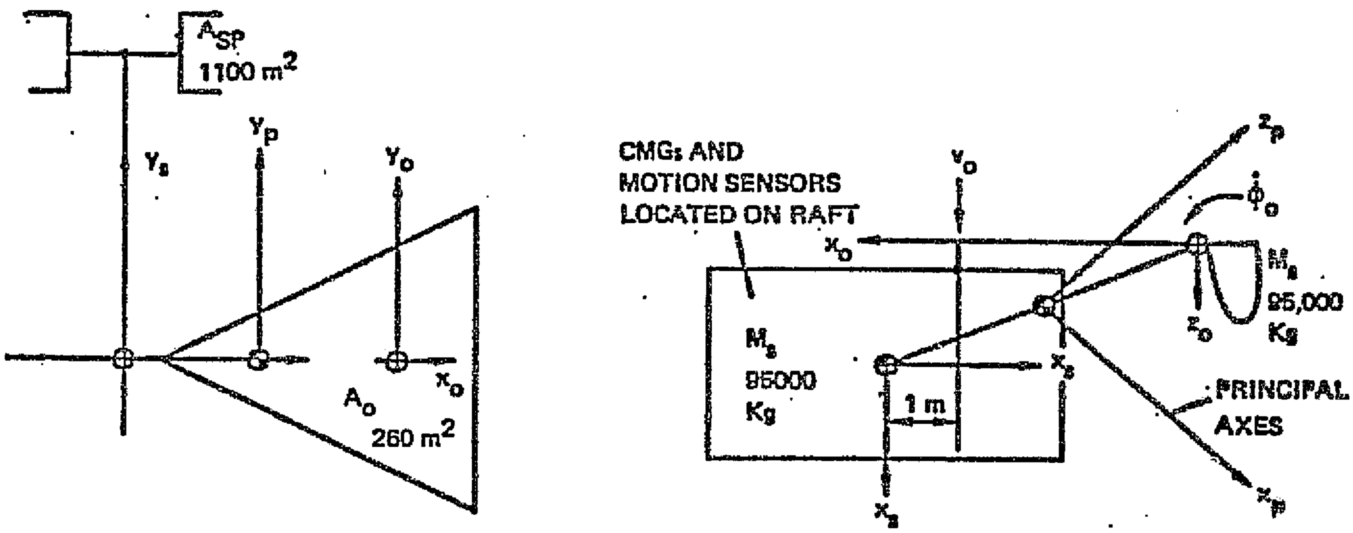

Figure 2.2-11. Orbiter Docking to Space Station Showing Preferred Configuration

Because the raft is rigid at frequencies of interest (0.5 - .5 Hz), colocation of ideal sensors and actuator on the raft will guarantee stability.

2. Damping of the structural modes is substantially augmented in most cases by the CMG core mounted controller. Damping of astromast torsional vibrations is not augmented by the core mounted controller.

3. The performance of the ideal reactive controller to suppress transient disturbances at levels of practical interest is limited only by the control authority. The issues addressed in the current simulation work are therefore related to the assumption of ideal (infinite band-width noise free) sensors and actuators.

4. Simulation shows no extreme motions of flexible elements when subject to the most severe shocks due to docking loads. The loads were modeled as impact forces at the docking interface. The maximum stress at the roots of the array boom and astromast are at least a factor of 100 less than the proportional limit stress.

5. Gimbal rate response to the test impulse doublet was found to be as high as 6^o/sec for controller bandwidth of .05 Hz. Skylab class gyros are rate limited to 4-6^o/sec. Therefore, if bandwidth above .05 Hz is required for the class of space station studied here, then three Skylab gyros is the minimum number to ensure accuracy of 100-200 arc sec under the assumed level of transient loads.

2.2.4 Conclusions

The conclusions of the study can be summarized as follows. Control of the free - free attitude modes using a regulator consisting of colocated CMG actuators and ideal rate and position sensors is asymptotically stable. However, the response of flex modes associated with the astromast is lightly damped with long settling time. If the resultant low amplitude vibrations are objectionable, then flex mode damping must be introduced. Investigation of passive damping techniques should be a first priority. With these results, the important issues of core station free - free mode attitude control using a simple controller without additional stability augmentation of the flex modes has been addressed.

2.2.5 Recommendations

Continuing effort in attitude control for space station should concentrate on defining control requirements during build-up and construction phases including configuration with the orbiter docked. Emphasis should be given to definition of control modes for each phase of evolution and schemes for managing the momentum envelope of candidate momentum transfer systems. Control modes would include electromagnetic sensing and actuation, momentum transfer, mass expulsion, attitude biasing, and appendage articulation.

2.3 DATA MANAGEMENT

Data management includes the data system hardware and software needed to provide all Space Station data processing, storage, and communications for onboard users, subsystems and payloads. This study was based on requirements determined in the Advanced Platform Systems Technology Study as shown in figure 2.3-1, and extended that work as summarized by the paragraphs that follow in this section.

2.3.1 Approach

Specifically, the three areas of data management extension for the Space Station Systems Technology Study are:

1. Mission configuration analysis.
2. Network Interface Unit (NIU) description.
3. Network Operating System (NOS) definition.

The purpose of the configuration analysis subtask was to assess the impact of candidate Space Station missions on the DMS, to ensure that the concepts developed in the previous study would meet all requirements. This analysis was used to develop a DMS model for future simulation studies, and also provided an input to subtasks two and three. The NIU and NOS were identified in the APSTS, and a cost benefits analysis was conducted to determine their potential value to the program. It was estimated that a potential savings of $176M could be realized if the LAN were developed, and if the onboard subsystems and payloads used the LAN hardware and software for data collection, processing, storage, and communications. The higher cost alternative would have each experimenter develop his own DMS hardware and software, followed by a systems integration step to make the payload compatible with the onboard data management system. This approach results in needless duplication of effort, when compared to the LAN. Also, the savings of $176M refers only to development costs. It is believed that the LAN would also yield significant savings in operational costs, due to the ease of maintenance resulting from its standardized, modular organization and due to the reduction in logistics requirements brought about by the use of a small set of common modules.

The first subtask under study task one, was to investigate the impact of possible Space Station mission configurations on the DMS, so that data communications bandwidths,

SUBSYSTEM	PROCESSING CHARACTERISTICS	STORAGE REQUIREMENTS	COMMUNICATIONS BANDWIDTH
CONTROL	FAULT TOLERANT COMPUTING SENSING, FILTERING ETC.	SMALL ARCHIVE SMALL BUFFERS	< 1 MBPS
COMMUNICATIONS	SWITCHING/MULTIPLEXING	LARGE BUFFERS	> 100 MBPS
DATA BASE	SEARCHING & SORTING	LARGE ARCHIVE	< 100 MBPS
DISPLAY	IMAGE GENERATION & SWITCHING	LARGE ARCHIVE LARGE BUFFERS	> 100 MBPS
MAINTENANCE	AUTO-TEST & SIMULATION	LARGE ARCHIVE	< 10 MBPS
MANIPULATOR	SENSING & MOTOR CONTROL	SMALL BUFFER	< 1 MBPS
SPACECRAFT TEST	SIMULATION & SWITCHING	LARGE ARCHIVE	> 100 MBPS
EXPERIMENT*	SENSING & SWITCHING	LARGE ARCHIVE LARGE BUFFERS	> 100 MBPS
AUDIO DISTRIBUTION	A/D & D/A CONVERSION	SMALL BUFFERS	< 10 MBPS
VIDEO DISTRIBUTION	ANALOG SWITCHING	NONE	> 100 MHz

*THEMATIC MAPPER, SYNTHETIC APERTURE RADAR ETC.
ARCHIVE: PERMANENT STORAGE FOR DATA RECORDING OR REFERENCE
BUFFER: HIGH SPEED TEMPORARY STORAGE

Figure 2.3-1 Data Processing, Storage and Communications Requirements

data storage capacities, processing requirements and interfacing requirements could be estimated. Three mission models were investigated, including Construction and Materials Processing Station (CAMPS), Communications and Data Management Station (CADMS), and Land, Ocean, and Atmospheric Research Station (LOARS).

After completion of the mission configuration analyses (subtask 1), the impact on the DMS hardware and software systems could be assessed more readily. This permitted the primary hardware element of the DMS to be analyzed and described in greater detail, as subtask 2; with the primary software element defined functionally, as subtask 3. These elements are the Network Interface Unit (NIU) and Network Operating System (NOS), respectively. Together, they comprise the onboard LAN that integrates the subsystems, instruments, user interfaces, and other equipment that require data management services. The NIU provides the system connection points or interfaces, while the NOS controls the data communications, storage, and processing activities of the DMS.

2.3.2 Technical Discussion

Figure 2.3-2 shows how the backbone local area network might fit into a typical space station configuration called the raft structure. The heavy lines are bundles of optical fibers, that interconnect the network interface units.

The topology can be described as a two-level hierarchy. The NIUs and their interconnections provide for communication between station modules, and form the upper level of the hierarchy. The devices connected to the links and buses within the modules, supported by the NIUs, form the lower level. This approach allows for modularity at both levels. The NIUs handle intermodule communications through standard berthing-port interfaces, allowing station modules to be plugged-in at any berthing port. At the lower level, sensors and medium-speed devices can be plugged into the NIUs by means of standard interface cards and standard buses.

The multi-star and graph fiber-optic backbone network topologies appear to be viable for the station; they are shown in figure 2.3-3. The diagram shows the two possible methods for interconnecting the station NIUs by means of fiber optics. The set of lines drawn above the boxes represents the interconnection topology formed by the use of four optical start couplers, located near NIUs C, D, E, and F. For example, the coupler located at NIU-C interconnects A through E, as shown by the lowest horizontal line. In this

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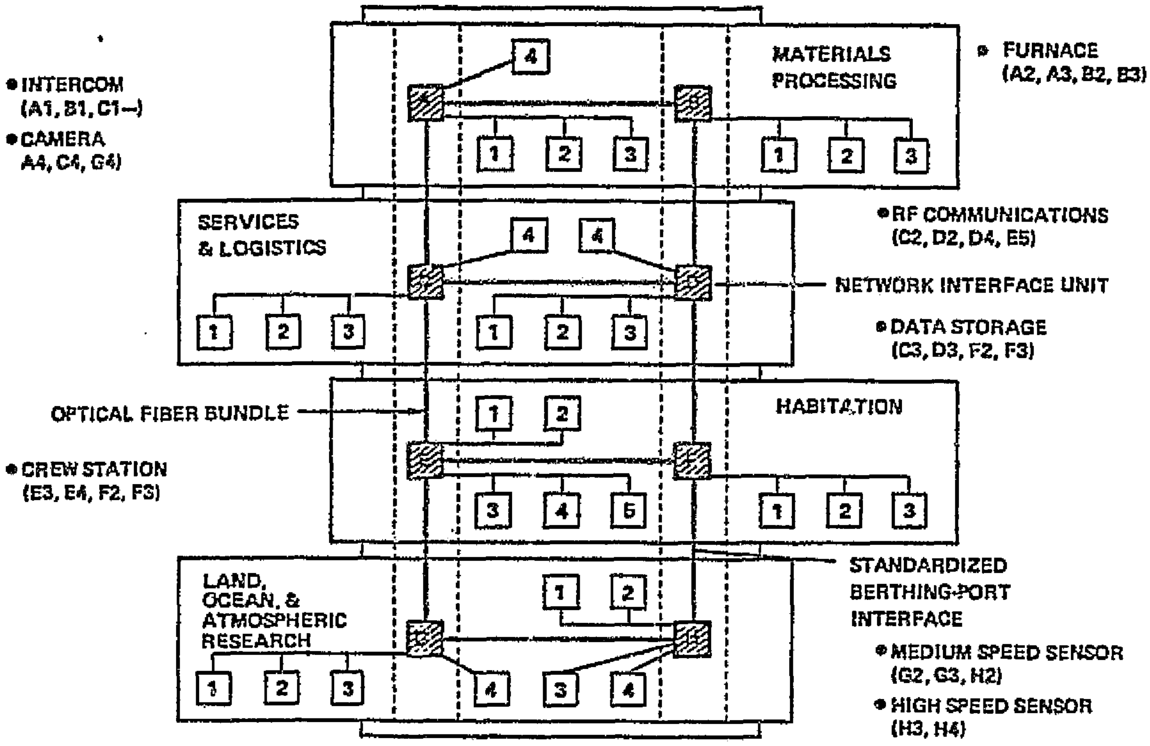
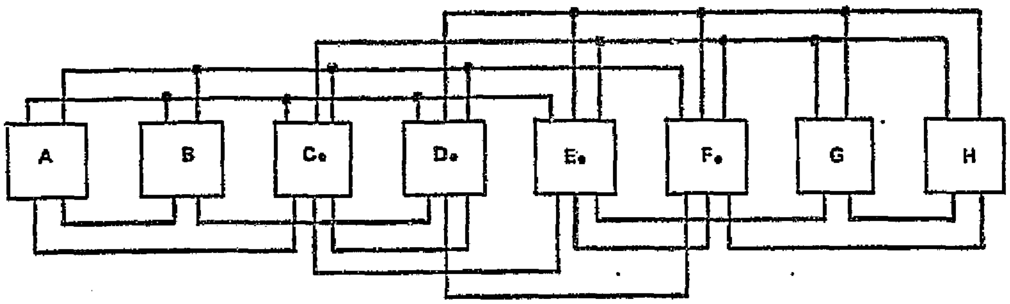


Figure 2.3-2 Fiber-Optic Backbone Network

RAFT CONFIGURATION

INTERCONNECTIONS FOR MULTI-STAR (4)



INTERCONNECTIONS FOR GRAPH

- BOTH TOPOLOGIES REQUIRE 20 OPTICAL TRANSCEIVERS
- BOTH NEED ROUTING AND RECONFIGURATION CAPABILITIES
- MULTI-STAR USES SHARED-BUS PROTOCOLS
- GRAPH USES TIME-DIVISION-MULTIPLE-ACCESS (TDMA)

Figure 2.3-3 Multi-Star Versus Graph Topologies

example, each of the couplers would interconnect a subset of five of the eight NIUs, so four five-port couplers would be required. The set of lines drawn below the boxes represents a point-to-point interconnection topology. Each link consists of a bidirectional channel, using two fibers with transmitters and receivers at opposite ends. Store-and-forward communications techniques are used, as opposed to the shared-bus techniques needed for the multi-star topology.

The transmitter and receiver logic is essentially the same in both cases, as shown in figures 2.3-4 and 2.3-5. These figures are block diagrams of the circuitry needed to implement optical transmitters and receivers, with the exception of the control logic. The transmitter converts digital data residing in memory to a serial bit-stream, encodes it with clock information, and uses the resulting signal to modulate an optical source. The receiver uses an optical detector to convert the signal back to an electrical form for decoding and conversion to a parallel word format that can be stored in a memory buffer. These examples use a 32-bit memory and a 100 MHz serial data rate, so the required memory cycle time (320 ns) is relatively slow.

The two configurations use different access protocols for multiplexing the communications media. The graph topology uses simple TDMA, while the multiple-star topology may use polling, contention, or token-passing. In a polling system, one of the NIUs functions as a controller, polling each of the other NIUs in sequence to enable them to transmit data, one after the other. In a contention scheme, each NIU acts independently and listens for activity on the communications channel. If the channel is not busy, the NIU can transmit; however, two may transmit almost simultaneously, resulting in a collision. They must detect such bus contention, back off, and try again after a random delay interval. In a token-passing configuration, the system is initialized so that one of the NIUs owns a logical token that enables it to transmit a packet. After completing its transmission, it then sends the token to another NIU, which may transmit and then pass the token to the next NIU in sequence.

At this point, no clear reason seems to exist for choosing a pure graph or a pure multiple-star topology over the other. It is believed that data management network simulation studies are needed before a final configuration can be chosen.

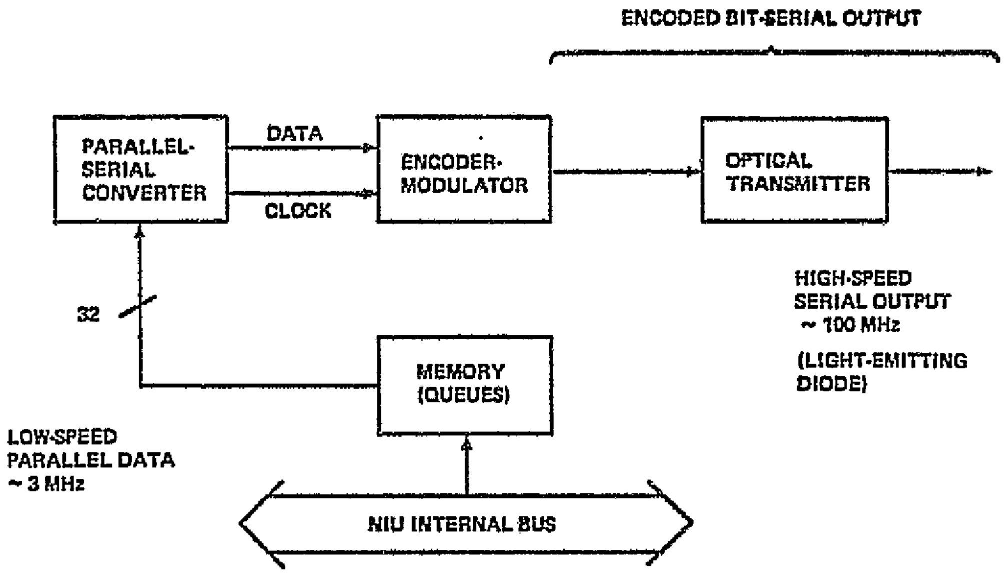


Figure 2.3-4 NIU: Transmitter Block Diagram

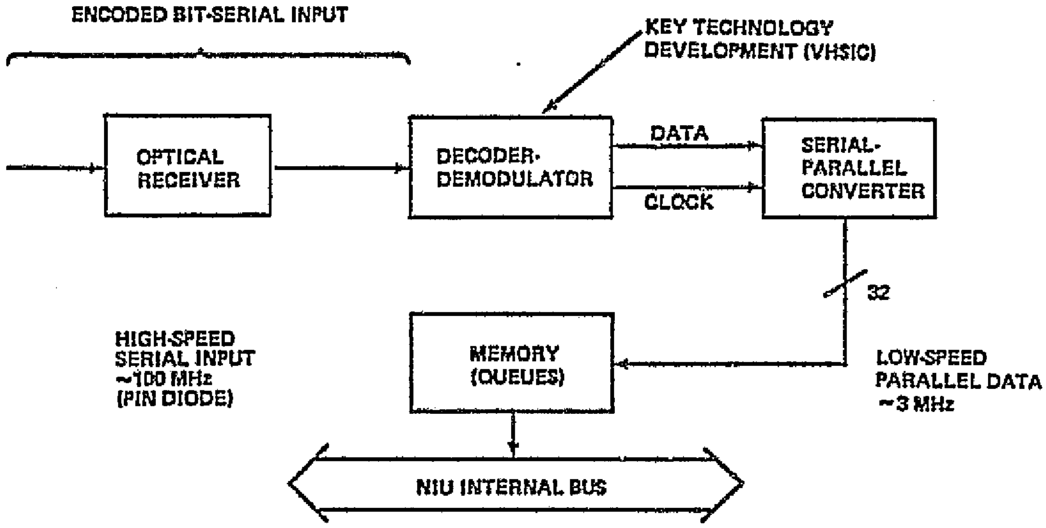


Figure 2.3-5 NIU: Receiver Block Diagram

2.3.2.1 Network Interface Unit (NIU)

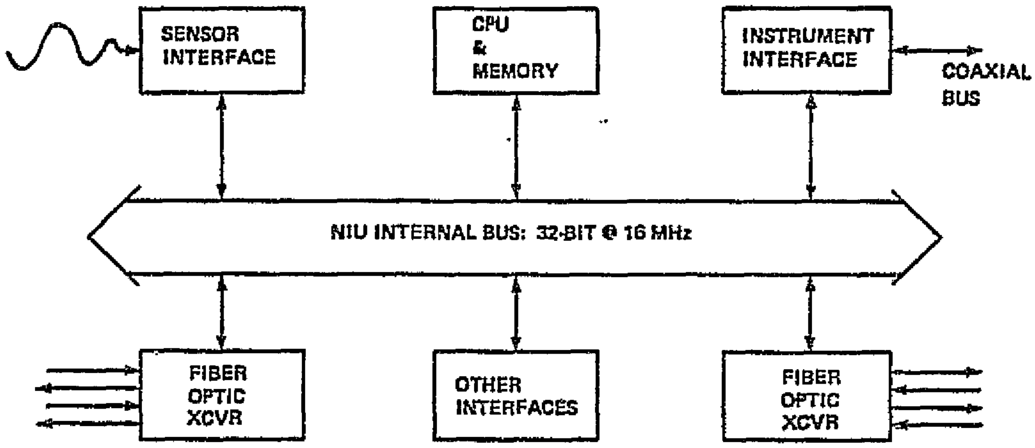
As shown in figure 2.3-6, the NIU is defined as a set of standard circuit cards that plug into a high-speed parallel data bus, housed in a rack-mountable chassis. The cards provide high-speed sensor control and data acquisition interfaces, instrumentation bus interfaces, fiber-optic intermodule communications transceivers, and many other types of input-output (I/O) interfaces and controllers.

The results of the study in this area indicate that the NIU should be modular, and should have a high performance potential. Space Station requirements will surely change over a period of many years, and the basic NIU chassis and high-speed parallel bus can support such changes and upgrades if they are designed with flexibility in mind.

Development of NIU modules will be a major project, because a dozen or more standard electronic modules will have to be specified, designed, and fabricated to meet most of the potential station applications, such as data acquisition or subsystem interfacing as follows:

1. NIU control processor and cache memory.
2. Fiber-optic communications transceiver.
3. Instrumentation bus interface controller.
4. RF communications transceiver interface.
5. Digital voice communications interface.
6. Crew station console/CRT interface.
7. High-speed sensor data buffer.
8. Magnetic tape mass memory controller.
9. Magnetic disk mass memory controller.
10. Color video & graphics I/O controller.
11. Analog I/O interface.
12. Discrete digital parallel interface.

Custom modules would also be needed, for specialized applications such as high speed sensors.



1. MODULAR NETWORK INTERFACE UNIT
2. STANDARDIZED INTERFACE MODULES
3. HIGH-SPEED INTERNAL PARALLEL BUS

Figure 2.3-6 NIU: Internal Organization

2.3.2.2 Network Operating System (NOS)

An operating system is the collection of software processes and functions that control computer systems, as shown in figure 2.3-7. In a distributed system environment, or in a local area network, the term network operating system (NOS) is frequently used, and has been adopted here. Aboard the Space Station, the NOS is conceived to have two major functions. First, it provides the operating environment for DMS users. Second, it manages the overall operation of the devices attached to the network, supporting status monitoring and control functions, and providing data storage, communications and processing services.

Development of an automated diagnostic and reconfiguration software system, as part of the NOS, appears to be a major task. So-called nonstop computer systems exist, but they are not in common usage and are not 100% effective. It would appear that more effort is needed if such a capability is to be available for use aboard the station. One of the most promising approaches to such a technology development is the use of software simulation to model the DMS and the NOS, and to test the response of the system to the injection of simulated faults.

As mentioned above, a prime development task is to determine how automated diagnostic and reconfiguration software can be implemented. Figure 2.3-8 shows how a DMS simulation process can be used to inject errors and hard faults into the model, to determine the impact on system functionality, and to test the performance of automatic reconfiguration algorithms.

The simulation package consists of several software modules, as shown in the diagram. The most important are the producers, servers, consumers, and the instrumentation module. Producers simulate the production of messages or packets that, in a real system, would be transmitted by the devices that make up the DMS. The servers simulate the behavior of the network communications components and software protocols. Consumers are the devices to which the messages or packets are sent. And finally, the instrumentation module performs data collection and simulated fault injection.

The simulation package will allow the use of modern CAE techniques in DMS design, in the same way and for the same reasons that integrated circuits are designed and simulated prior to fabrication. Simulation can give excellent indication of system performance, before major resources are committed to production; and, various concepts can be traded and compared to produce an optimal design.

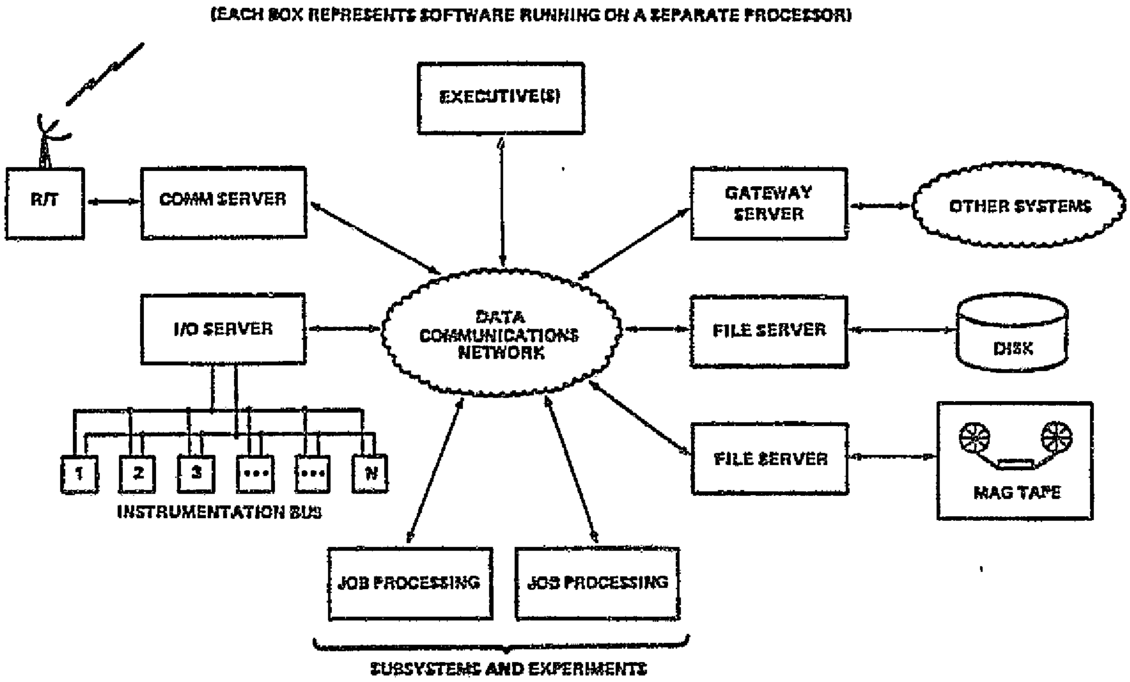


Figure 2.3-7 Network Operating System Example

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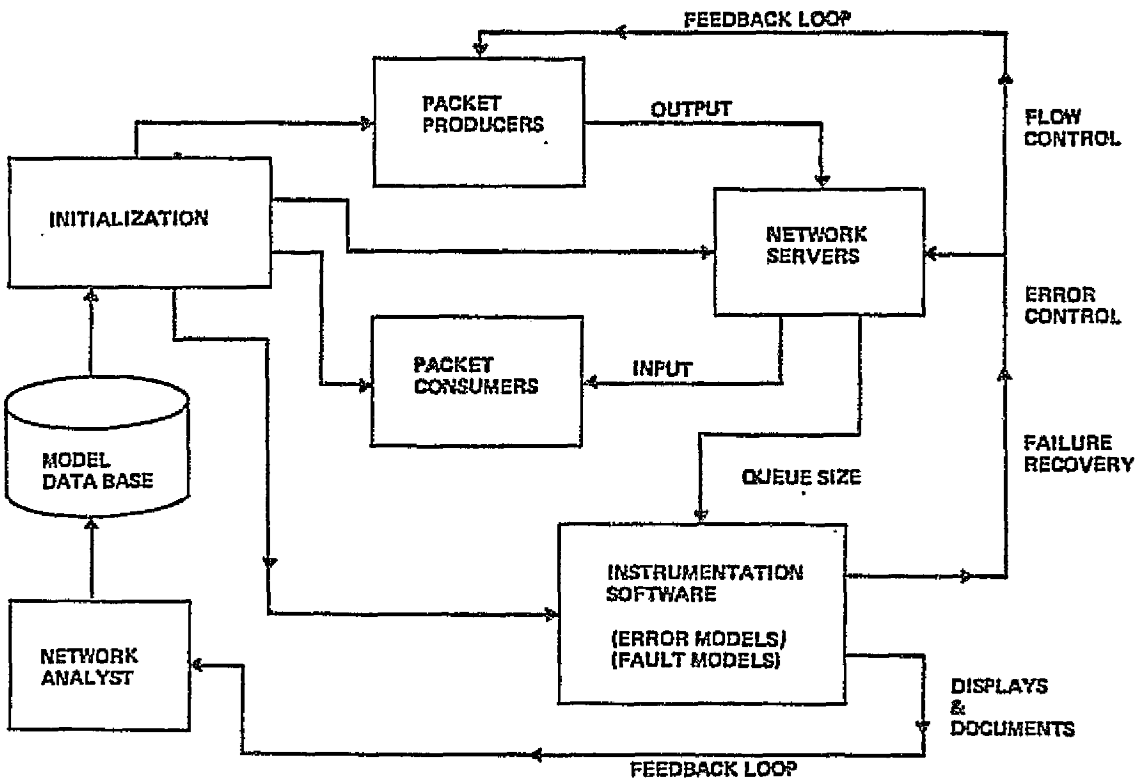


Figure 2.3-8 DMS Closed Loop Simulation

2.3.3 Conclusions and Recommendations

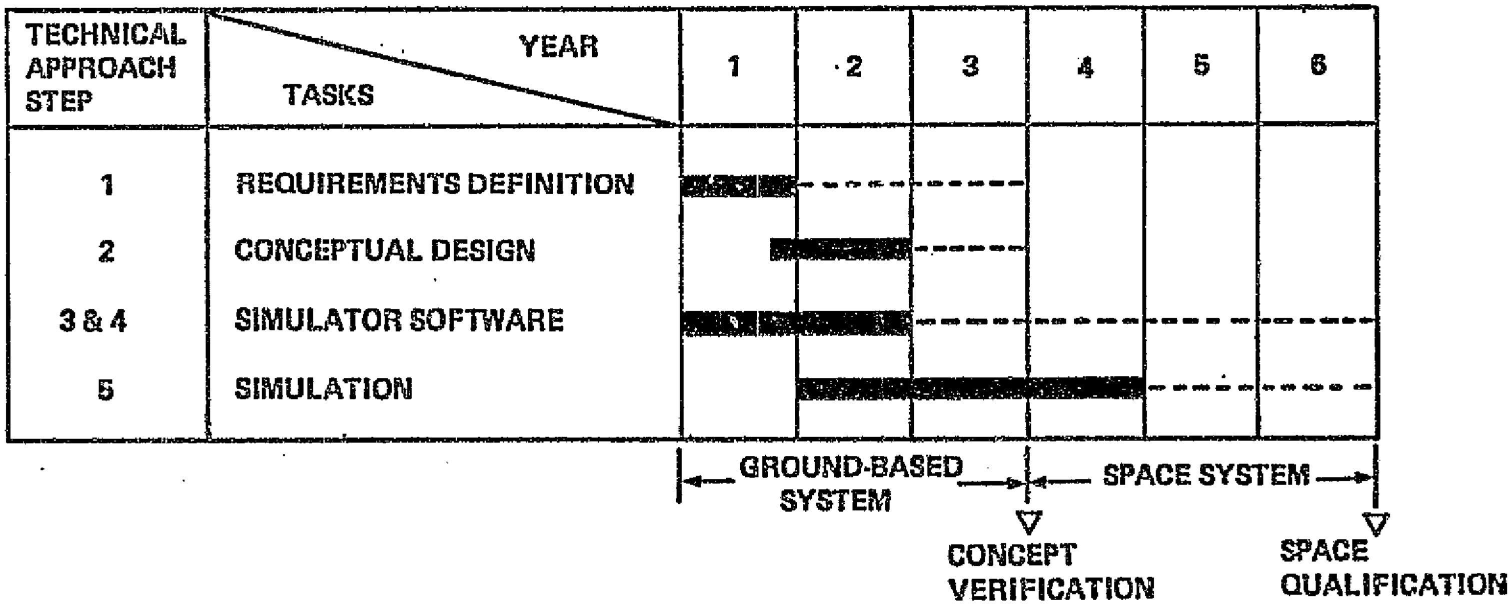
The work performed during the data management study led to conclusions in data management system configurations, system hardware (NIU), and system software (NOS). Three potential mission configurations were analyzed, with the Land, Ocean, and Atmospheric Research Station (LOARS) model developed in enough detail for simulation studies to commence. The NIU was analyzed to the point where component technologies could be identified; and the NOS was defined to a level of detail that included individual software modules and their functional interrelationships. These analyses were then used in the second part of the study, task 2, to help in the evaluation of the need for each. In the data management study, 16 technology areas were identified during task 1 and were scored in 5 categories, with a rating of 0, 10, or 20. These scored technology areas are listed on figure 2.3-9. On that figure, a technology needed early in the program is more critical to success than one that is needed late, so a score of 20 was assigned. The total scores give a rough estimate of the program criticality of each of the 16 technologies. That is, an area with a high score is an area that may have a greater program impact. An area with a low score, such as the high-speed sensor data buffer, may still be important; however, low cost and risk, combined with a late need and relatively short lead time mean that the relative program impact may be quite low.

The simulator, the NIU, and the NOS are the key elements of the DMS that have been identified and described in detail during the Advanced Platform Systems Technology study and those elements still appear to provide the greatest cost savings to the program. The total cost of development for the three items is $22.45M over six years. If the development cost savings to the program is $176M primarily in reduced systems integration costs, then the ratio of benefits (savings) to cost is 7.9. That is, for every dollar spent on network simulation, hardware (NIU) and software (NOS), NASA can expect savings in DMS development cost of almost eight dollars. The potential savings in operating costs are also considered to be quite significant, and are worth investigating in future studies. The main conclusion is that in the Space Station DMS development some technologies are needed before others and are, in fact, needed to facilitate development of others.

SCORING		NEED	LEAD	COST	RISK	VALUE
	20	EARLY	LONG	HIGH	HIGH	HIGH
	10	MID	MID	MID	MID	MID
	0	LATE	SHORT	LOW	LOW	LOW

TECHNOLOGY AREA	NEED	LEAD	COST	RISK	VALUE	TOTAL
HARDWARE						
•STANDARD CARDS	20	10	20	10	20	80
•STANDARD BUSES	20	20	10	0	20	70
•F.O. TRANSCEIVERS	10	10	10	10	10	50
•DECODER CHIP	10	10	10	10	10	50
SOFTWARE						
•SIMULATOR	20	10	10	20	20	80
•EXECUTIVES	20	10	20	10	20	80
•PROTOCOLS	20	10	10	10	20	70
•DIAGNOSTICS	10	0	0	0	10	20
GENERAL SYSTEM						
• PAYLOAD DEV. SYS.	20	20	10	10	20	80
• MAINTENANCE EXP.	10	10	10	20	20	70
• IMAGE PROCESSOR	0	20	20	20	10	70
• CONTROL SOFTWARE	10	10	10	10	10	50
• INTERFACE TEST SET	20	10	10	0	10	50
• CREW WORKSTATION	10	0	0	0	10	20
• DISK/BUBBLE MEM.	10	0	0	0	10	20
• DATA BUFFER	0	0	0	0	10	10

Figure 2.3-9. Criticality of Technologies



NOTES: (1) DEVELOPMENT SCHEDULE BASED ON SCHEDULE FROM VOLUME IV, "ADVANCE PLATFORM SYSTEMS TECHNOLOGY STUDY"

(2) SCHEDULES BEGIN AT ATP ON NIV. IF ATP OCCURRED IN 4TH QUARTER OF 1ST YEAR OF SYSTEM

(3) DARK LINES INDICATE HEAVY EMPHASIS. DOTTED LINES INDICATE COORDINATION EFFORT.

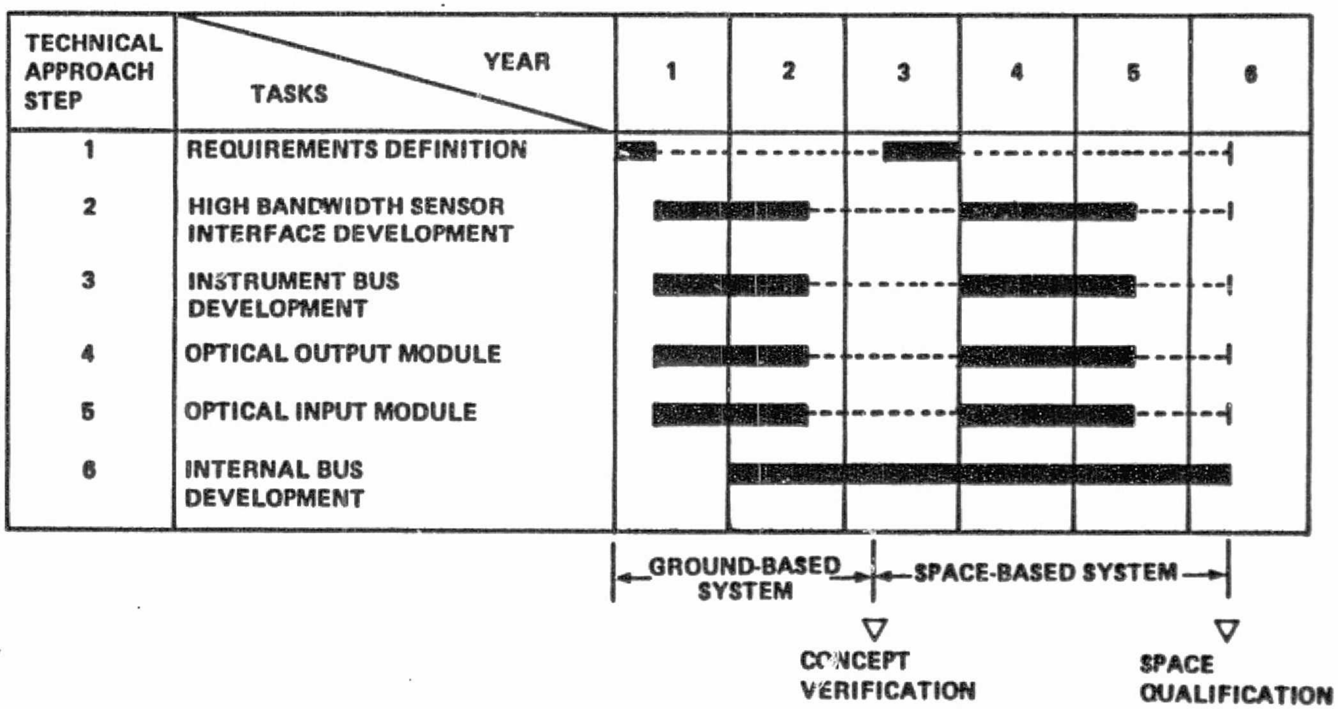
Figure 2.3-10 Schedule for Data Management System Simulation Program

Table 2.3-1 Resources for Data Management System Simulation Program

TECHNICAL APPROACH STEP	TASK \ YEAR FROM ATP	1	2	3	TOTAL (GROUND BASED SYSTEM)	4	5	6	TOTAL (SPACE-BASED SYSTEM)	OVERALL TOTAL
1	REQUIREMENTS DEFINITION	700	350	300	1350	–	–	–	–	1350
2	CONCEPTUAL DESIGN	200	800	350	1350	–	–	–	–	1350
3 & 4	SIMULATOR SOFTWARE	650	750	200	1600	100	100	100	300	1900
5	SIMULATION		500	750	1250	650	200	150	1000	2250
TOTAL		1550	2400	1600	5550	750	300	250	1300	6850

NOTES: (1) FIGURES IN $1000 (1983)

(2) ESTIMATES TAKEN FROM VOLUME IV, "ADVANCED PLATFORM SYSTEMS TECHNOLOGY STUDY"



NOTES: (1) NIU DEVELOPMENT SCHEDULE BASED ON SCHEDULE FROM VOLUME IV, "ADVANCE PLATFORM SYSTEMS TECHNOLOGY STUDY"

(2) SCHEDULES BEGIN AT ATP ON NIU. IF ATP OCCURRED IN 4TH QUARTER OF 1ST YEAR OF SYSTEM DEVELOPMENT SCHEDULE, MAJOR MILESTONES WOULD COINCIDE. SEE REFERENCE ABOVE

(3) DARK LINES INDICATE HEAVY EMPHASIS. DOTTED LINES INDICATE COORDINATION EFFORT.

Figure 2.3-11 Schedule for Network Interface Unit Technology Advancement Program

Table 2.3-2 Resources for Network Interface Unit Technology Advancement Program

TECHNICAL APPROACH STEP	TASKS \ YEAR	1	2	3	TOTAL (GROUND-BASED SYSTEM	TOTAL (SPACE-BASED SYSTEM)	OVERALL TOTAL
1	REQUIREMENTS DEFINITION	80	10	10	100	400	500
2	HIGH BANDWIDTH SENSOR INTERFACE DEVELOPMENT	120	120	10	250	1000	1250
3	INSTRUMENT BUS DEVELOPMENT	225	225	50	500	2000	2500
4	OPTICAL OUTPUT MODULE	95	95	10	200	1000	1200
5	OPTICAL INPUT MODULE	95	95	10	200	1000	1200
6	INTERNAL BUS	–	200	350	550	2400	2950
	TOTALS	615	745	440	1800	7800	9600

NOTES: (1) SCHEDULE BEGINS AT ATP ON NETWORK INTERFACE UNIT

(2) TOTALS TAKEN FROM VOLUME IV, "ADVANCED PLATFORM SYSTEMS TECHNOLOGY STUDY"

(3) SPACE-BASED SYSTEM (DEVELOPMENT UP TO SPACE QUALIFICATION SHOWN FOR REFERENCE). DETAILS OF TIME PHASING CAN BE FOUND IN REFERENCE OF NOTE 2.

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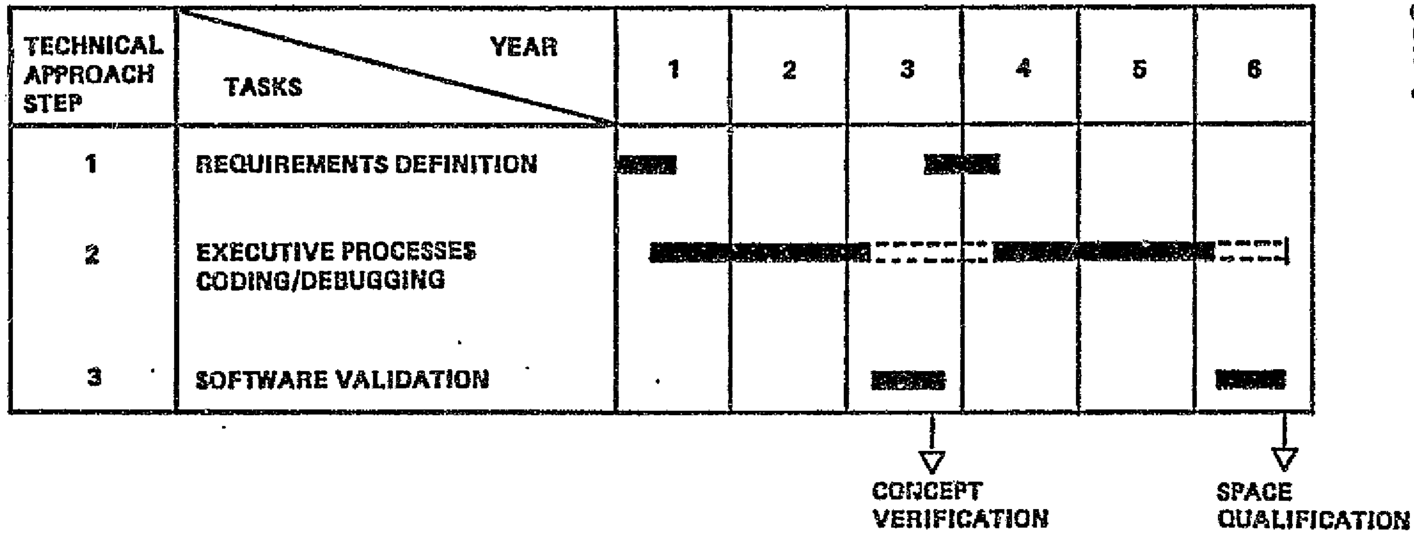

NOTES: (1) NOS DEVELOPMENT SCHEDULE BASED ON SCHEDULE FROM VOLUME IV, "ADVANCE PLATFORMS SYSTEMS TECHNOLOGY STUDY"

(2) SCHEDULES BEGIN AT ATP ON NIU. IF ATP OCCURRED IN 4TH QUARTER OF 1ST YEAR OF SYSTEM DEVELOPMENT SCHEDULE, MAJOR MILESTONES WOULD COINCIDE. SEE REFERENCE ABOVE.

(3) DARK LINES INDICATE HEAVY EMPHASIS. DOTTED LINES INDICATE COORDINATION EFFORT.

Figure 2.3-12 Schedule for Network Operating System Technology Advancement Program

Table 2.3-3 Resources for Network Operating System Technology Advancement Program

TECHNICAL APPROACH STEP	YEAR / TASKS	1	2	3	TOTAL (GROUND-BASED SYSTEM)	TOTAL (SPACE-BASED SYSTEM)	OVERALL TOTAL
1	REQUIREMENTS DEFINITION	200	–	–	200	200	400
2	EXECUTIVE PROCESSES CODING/DEBUGGING	900	1200	400	2500	1900	4400
3	SOFTWARE VERIFICATION	–	–	200	200	1000	1200
TOTALS		1100	1200	600	2900	3100	6000

NOTES: (1) SCHEDULE BEGINS AT ATP ON NETWORK OPERATING SYSTEM

(2) TOTALS TAKEN FROM VOLUME IV, "ADVANCED PLATFORM SYSTEMS TECHNOLOGY STUDY"

(3) SPACE-BASED SYSTEM (DEVELOPMENT UP TO SPACE QUALIFICATION SHOWN FOR REFERENCE). DETAILS OF TIME-PHASING CAN BE FOUND IN REFERENCE OF NOTE 2.

2.3.4 Technology Advancement Plans

As a result of system trades in the data management area, several components have been pinpointed as offering significant benefits in cost and performance. In addition, some items were selected for advancement because they were necessary to be built for fiber-optic backbone data management system (as described in Volume II) rather than because they were more cost effective than other options. For instance, in the case of the network operating system, there is no alternative but to have one.

The data management requirements of the early and evolutionary Space Station configurations represent the near-term and evolutionary goals of the data network. Also, the items below were selected for technology advancement because they represent those items of a fiber optics data network that are critical since they might not otherwise be developed in time for a FY 87 new start on the Space Station. The system development and application area will involve a system simulation that is essentially the first generation network. The network interface unit and operating system areas are critical items of the second generation network development.

Figures 2.3-10, -11, and -12 and tables 2.3-1, -2, and -3 provide schedules and resource planning information respectively for the three data management advancement programs.

2.4 LONG-LIFE THERMAL MANAGEMENT

The objective of the present long-life thermal management study was to identify heat transport system technologies that increase performance, enhance system life, and reduce system weight and cost. Emphasis was placed on two-phase heat transport systems that offer significant potential benefits. These systems absorb and reject heat at a near constant temperature. This simplifies the thermal interfaces and allows thermal loads to be placed at any location that provides a high degree of flexibility in reconfiguring the space station. Reduced pump power requirements and heat transport by latent heat of vaporization provide size and weight reductions compared to a conventional pumped liquid loop heat transport system. These comparisons made possible the identification of three new technology areas requiring advancement.

The study approach, technical discussion of study and results are summarized in the following sections.

2.4.1 Approach

The trade study was divided into subtasks as outlined below:

1. Define baseline pumped two-phase heat transport system.
2. Optimize baseline system.
3. Identify optional systems.
    a. Pumped liquid loop.
    b. Capillary two-phase.
    c. Alternate two-phase pumping concepts.

The trade study groundrules and the basic heat transport systems studied are defined in section 2.4.2. The summary of results are presented in section 2.4.3.

2.4.2 Technical Discussion

The following paragraphs provide a technical summary of the study conducted for Long-Life Thermal Management.

2.4.2.1 Groundrules for Study

The following basic groundrules were established for the study:

1. Heat load: 25-150 kW.
2. Transport distance: approximately 150 ft.
3. Grumman Space Constructable Radiator 1.2 lb/ft^2.
4. Power penalty: 350 lb/kW.
5. Heat transport fluids:
    a. Two-phase: ammonia.
    b. Pumped liquid: Freon 11, Freon 114, ammonia.
6. Low temperature (about 40°F) heat rejection for metabolic and battery heat loads.
7. High temperature (about 80°F) heat rejection for remaining loads.
8. Radiation sink temperature: 415°R.

9. Pumped water heat transport loop inside pressurized modules.
10. Elements for each system:
    a. Radiator.
    b. Cold plates.
    c. Pressurized module interfaces.
    d. Transport loop.
11. Thermal storage interface inclusion is beyond scope of study.

During the course of the study, only minor differences were found between the results for Freon 11 and Freon 114. Consequently, the detailed analyses were completed for Freon 11 only. It also became apparent that a two-phase water heat transport system inside the pressurized modules offered benefits; that concept was added to the study.

2.4.2.2 Heat Transport Systems

Figure 2.4-1 shows the basic heat transport systems that were analyzed in this study. The baseline is a pumped two-phase system with a liquid and vapor lines. A mechanical pump is used to pump the liquid condensate from the radiator to the heat source heat exchangers (evaporators). Control valves are used to meter liquid flow to the heat exchangers. The fluid vapor flows to the radiator when it condenses as the waste heat is radiated to space. The thermal storage unit is used to provide load leveling and efficient use of the radiator. (As noted previously, a detailed analyses of the thermal storage interface was beyond the scope of the study.)

The capillary two-phase system is similar to the baseline system, except pumps and valves are not required. The capillary wicks in the heat exchangers provide the required pumping action. The pumped liquid loop is similar to the baseline system except that the heat is transported as sensible heat rather than as latent heat of vaporization.

Alternate pumping concepts were briefly considered for the baseline pumped two-phase system. One concept would use an osmotic pump in the liquid line. The liquid would consist of a solvent and solution separated by a semipermeable membrane. The osmotic pressure across this membrane causes solvent flow through the membrane into the solution. The solvent evaporates from the solution at the evaporators, condenses in the radiator and returns to the membrane. The other concept considered uses an ion drag pump. This pump uses a high voltage probe to generate and accelerate ions in the fluid. These ions exchange momentum with the fluid and produce the pumping action.

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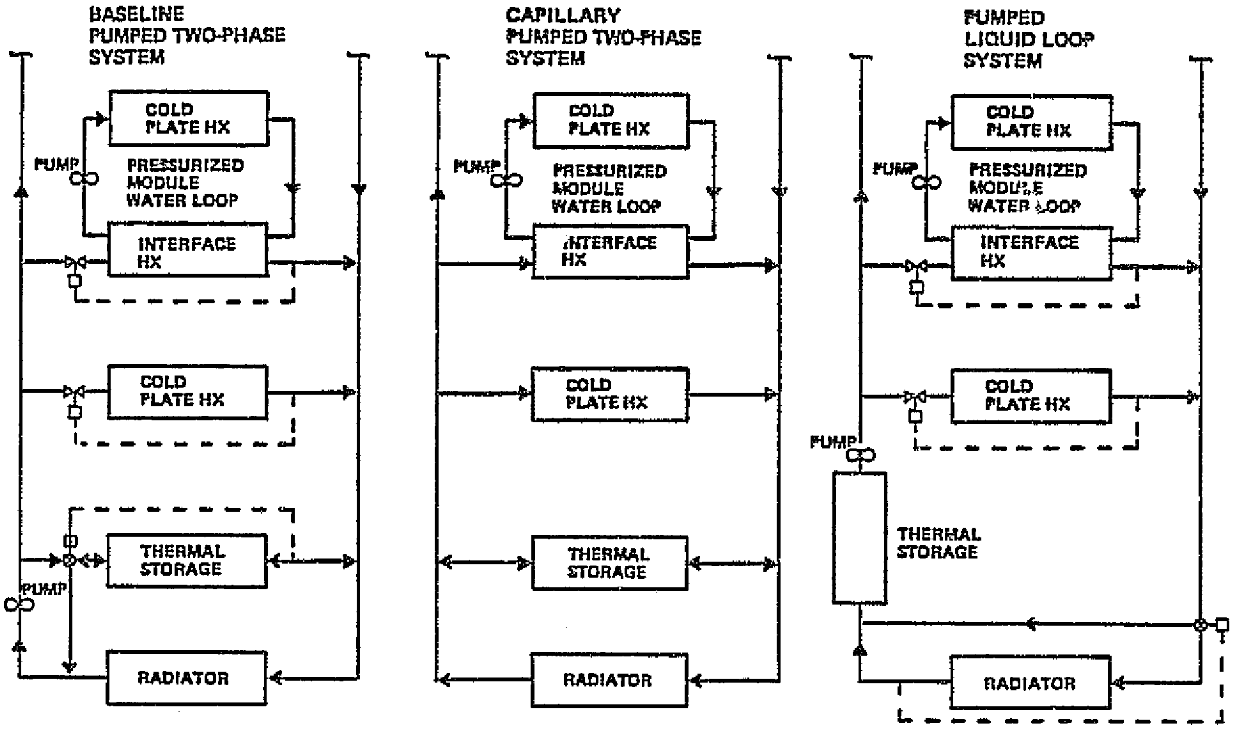

Figure 2.4-1 Heat Transport Systems

2.4.2.3 Effect of Two-Phase Water System In Pressurized Modules

The interface between the two-phase heat transport bus and the pumped water loops in the pressurized modules results in a lowering of the bus temperature in order to minimize system weight. The reason for this is that the water temperature change must be less than the temperature difference between equipment and bus. Consequently, because the water loop transports sensible heat, higher flow rates (and higher weights) are incurred as the temperature difference decreases. A two-phase water heat transport system allows a higher bus temperature and potentially lighter weight system.

2.4.2.3.1 Two-Phase Water Heat Exchanger and Line Sizing

The two phase heat exchanger weights were based on a detailed analysis conducted as part of the study. Because the water vapor density is low for the temperature range considered, the vapor pressure drop (in the vapor line between the equipment and interface heat exchanger) effect on vaporization (condensation) temperature was included in the analyses.

For the high temperature heat rejection system case the vapor line was fixed at an inside diameter of 2.25 inches and the liquid line at 0.5 inch inside diameter. These line sizes result in an overall head difference of about 1 inch, which is compatible with capillary pumping. The vapor line pressure drop produces a difference between vaporization temperature, at the equipment heat exchanger, and condensation temperature, at the interface heat exchanger of 1.76°F. The heat exchangers were optimized as a function of equipment to bus temperature difference that included this fixed vaporization temperature difference.

The effect of pressure drop on vaporization temperature is more pronounced in the low temperature heat rejection case. In this case the vapor line size was optimized in conjunction with heat exchanger optimization to provide the lowest weight system for a given humidity control unit to bus temperature difference. The liquid line size was fixed at 0.25 inch O.D. with 0.02 inch wall.

2.4.2.3.2 Effect on System Weight

Figure 2.4-2 shows the effect of incorporation of two-phase water heat transport systems in the pressurized modules on the high temperature two-phase ammonia system element weights. The minimum total weight now occurs at a bus temperature of 79°F compared to the 70°F optimum for the system with pumped water loops. A detailed schematic showing the effects on the two-phase water system is shown in figure 2.4-3. The main bus sizes and weights remain unaffected. The equipment cold plate weights are increased due to the higher bus temperature. The radiator and pressurized module component weights are significantly reduced. The total system weight is 828 lb less than that for the system with pumped water loops.

The effects on the low temperature heat rejection system are shown in figures 2.4-4 and 2.4-5. The optimum bus temperature for this case is 37.5°F compared to 36°F for the case with pumped water loops. As in the high temperature case the bus weight remains unaffected, the battery cold plate weight is increased and the other component weights are reduced. The total weight is 79 lb less than that for the pumped water loop system.

2.4.3 Summary of Results

The weights for the various heat transport systems, applied to the baseline space station, are summarized in table 2.4-1. The pumped two-phase ammonia system used in conjunction with two-phase water heat transport inside the pressurized modules is the lightest system. The corresponding capillary two-phase system is 359 lb heavier. The pumped two-phase system with pumped water loops inside the modules is 907 lb heavier. The pumped liquid ammonia system is heavier by 2126 lb and the pumped freon system is heavier by 3699 lb. The total radiator area required is: 6186 ft^2 for two-phase ammonia systems in conjunction with two-phase water loops; 6690 ft^2 for two-phase ammonia systems with pumped water loops; 7900 ft^2 for pumped liquid ammonia system; and, 8035 ft^2 for pumped freon system.

2.4.4 Cost and Benefits Analysis

In the final report of the study completed in April of 1983 a cost and benefits assessment was given for developing thermal storage systems for both pumped liquid and two-phase heat transport concepts. The result indicated that those technology advancements were

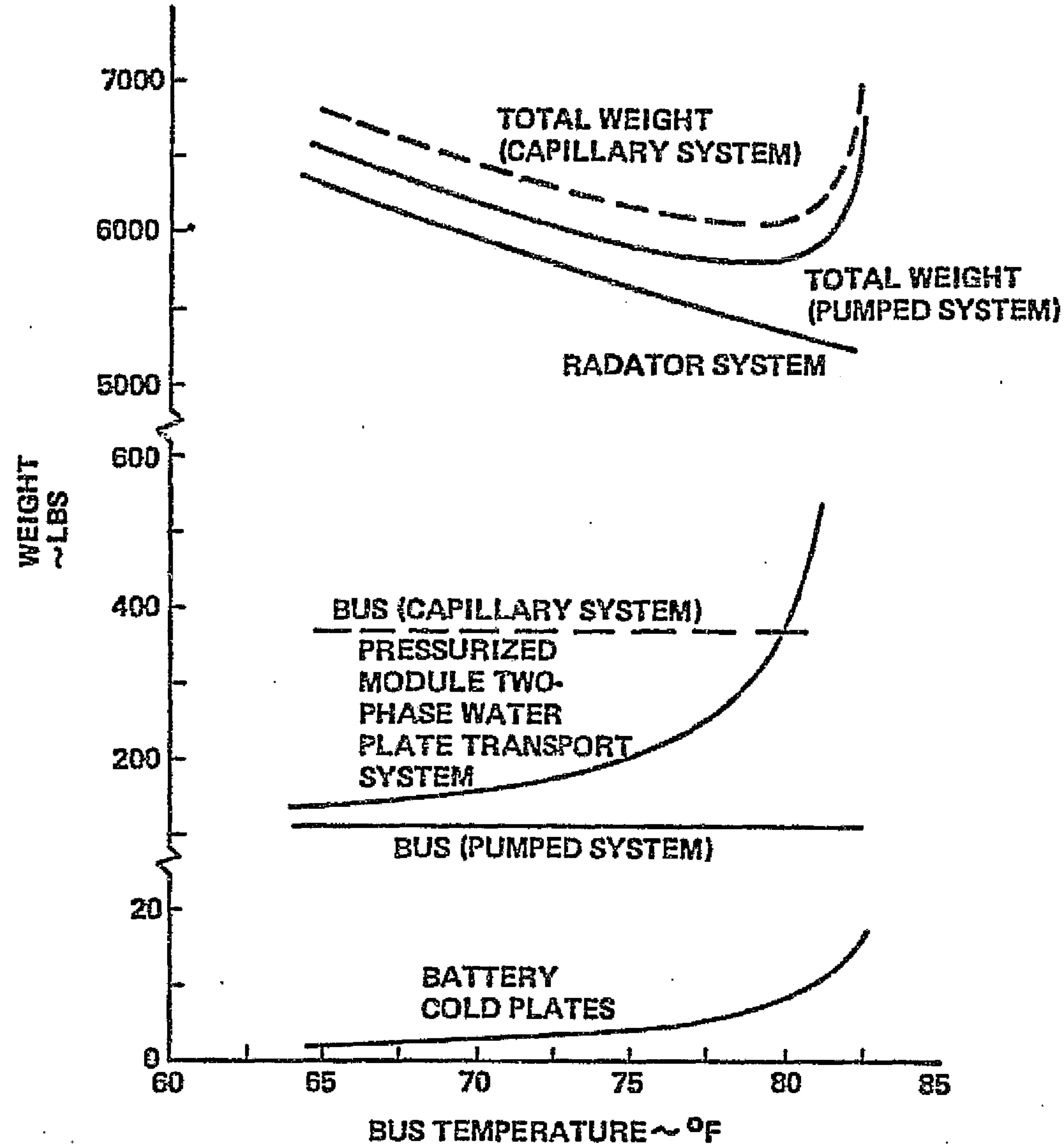

Figure 2.4-2 High Temperature Two-Phase Ammonia Bus with Two-Phase Water Loops

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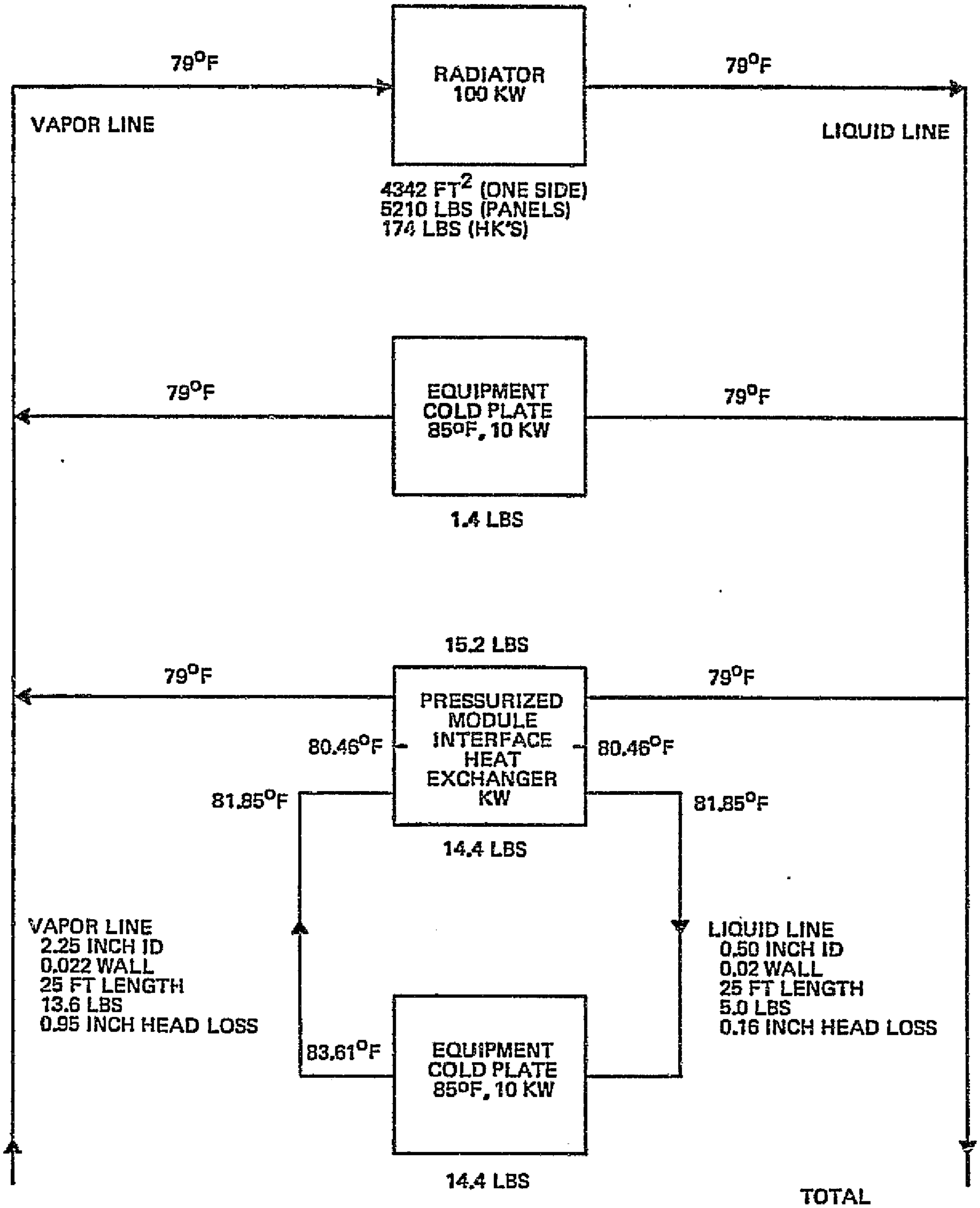

TOTAL

	PUMPED	CAPILLARY
EQUIP	5780 LBS	6073 LBS
POWER	88 WATTS	—
TOTAL	5811 LBS	6073 LBS

Figure 2.4-3 Effect of Two-Phase Water Heat Transport System on High Temperature Bus

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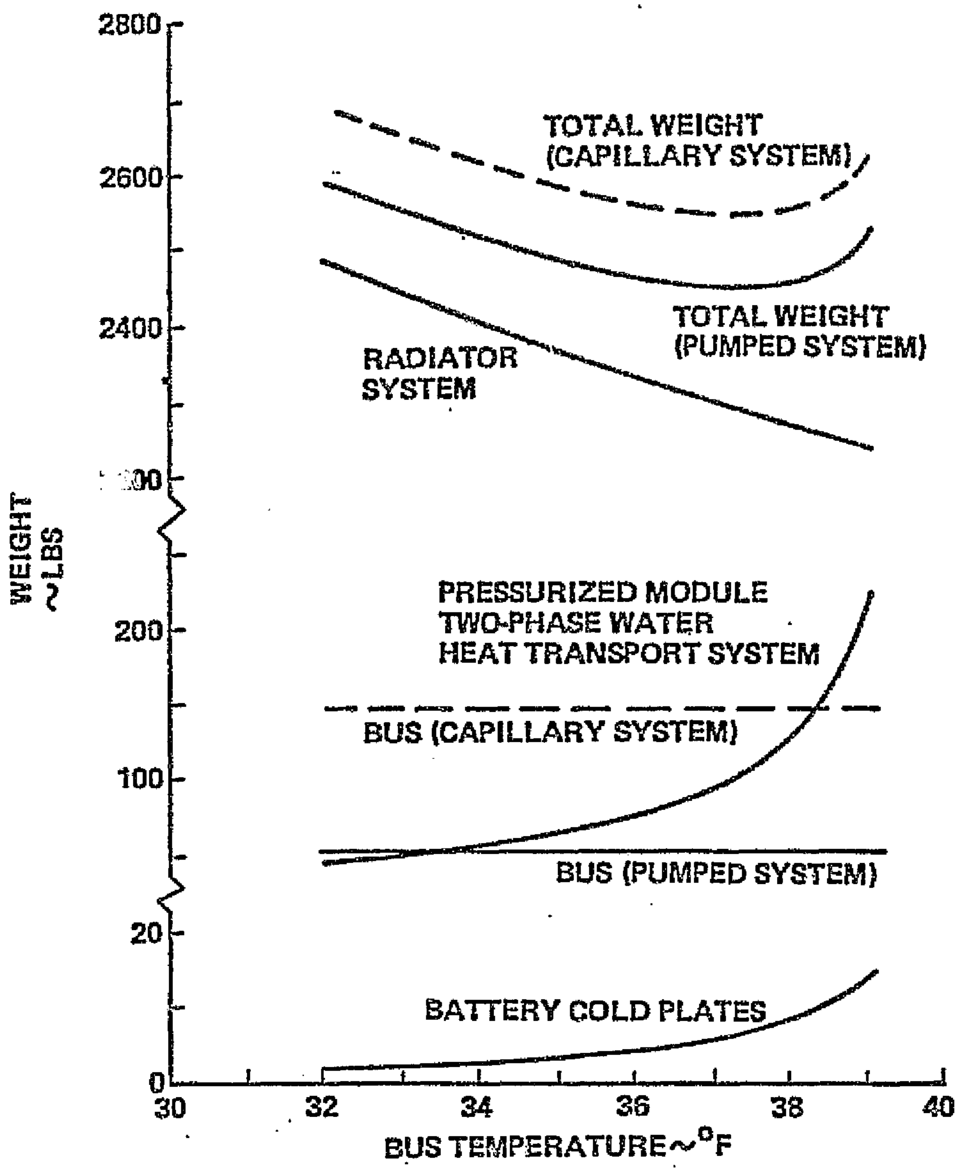
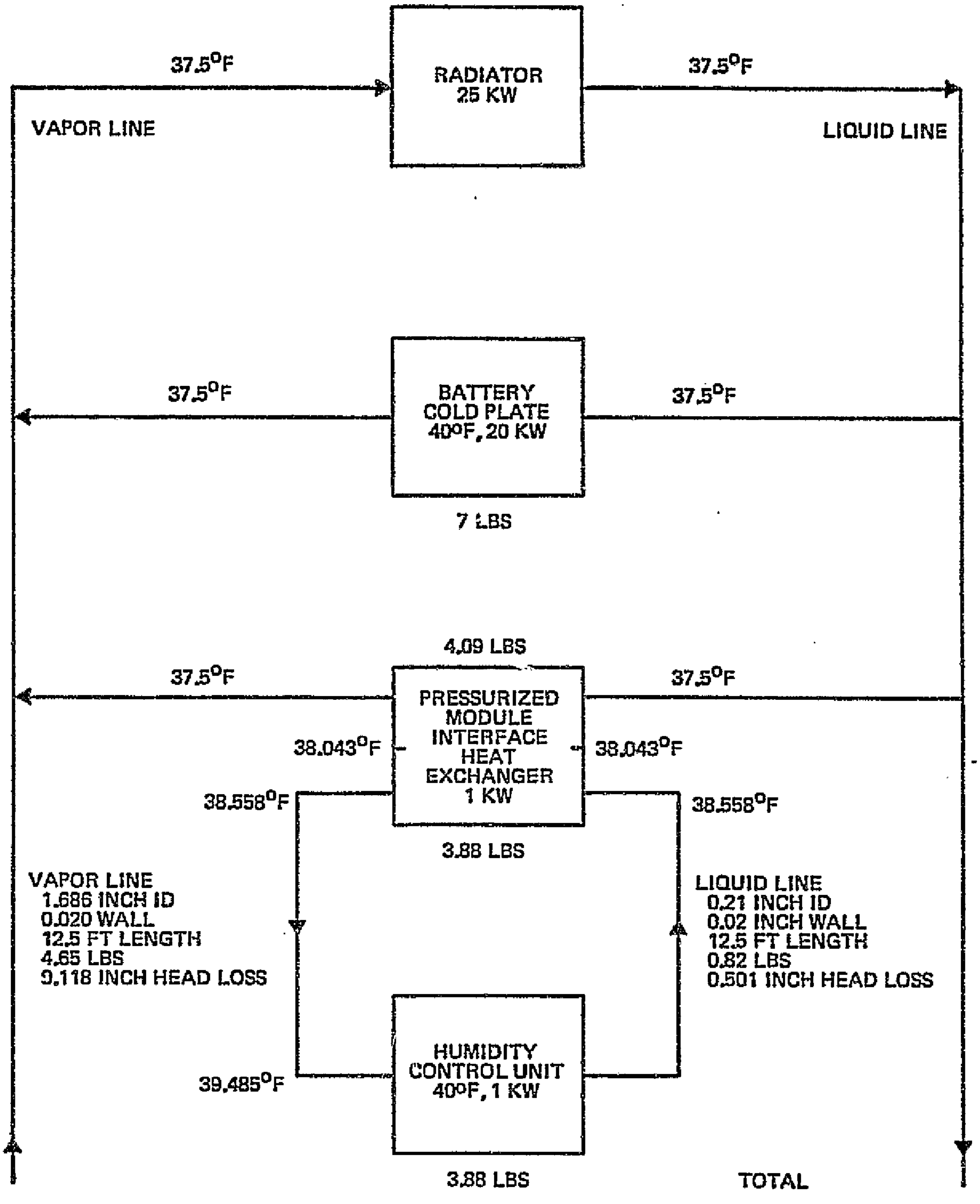


Figure 2.4-4 Low Temperature Two-Phase Ammonia Bus with Two-Phase Water Loops



	PUMPED	CAPILLARY
EQUIP	2416 LBS	2528 LBS
POWER	42 WATTS	——
TOTAL	2431 LBS	2528 LBS

Figure 2.4-5 Effect of Two-Phase Water Heat Transport System on Low Temperature Bus

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Table 2.4-1 System Weight Comparison

	TRANSPORT LOOP	COLD PLATES	MANNED MODULE WATER LOOPS	HX's	RADIATOR	TOTAL WEIGHT
PUMPED LIQUID LOOP						
FREON 11	742	119	59	762	10259	11941
AMMONIA	207	13	59	285	9804	10368
TWO-PHASE AMMONIA						
PUMPED						
HIGH TEMP	107	3	171	400	5958	6639
LOW TEMP	52	4	46	70	2338	2510
TOTAL	159	7	217	470	8296	9149
CAPILLARY						
HIGH TEMP	369	SAME AS PUMPED TWO-PHASE				6901
LOW TEMP	149					2607
TOTAL	518					9508
TWO-PHASE AMMONIA SYSTEM WITH TWO-PHASE WATER SYSTEM IN MANNED MODULES						
PUMPED						
HIGH TEMP	107	7	93	220	5384	5811
LOW TEMP	52	7	27	59	2286	2431
TOTAL	159	14	120	279	7670	8242
CAPILLARY						
HIGH TEMP	369		SAME AS ABOVE			6073
LOW TEMP	140					2528
TOTAL	518					8601

NOTE: 125 KW HEAT LOAD (100 KW AT 85°F; 20 KW BATTERY & 5 KW METABOLIC AT 40°F)
300 FT TOTAL TRANSPORT DISTANCE

among the most desirable of the ones identified in that study. It was indicated in that study that development costs for the two-phase system would be 50% higher due to the complexity of:

a. Phase change material packaging.
b. Thermal interface with the heat transport system.

In the current study, a further assessment of the pumped liquid versus two-phased heat transport system was conducted. Two technologies were identified for advancement specifically to support the development of a two-phase system. These are:

a. Two-phase water thermal transport loops for inhabited environment.
b. Heat exchanger for liquids in nearly saturated state in zero gravity.

The quantifiable benefits of these advancements are (1) that the two-phased system is less complex than the pumped liquid system, (2) that the two-phased system weighs less than the pumped liquid system, which means lower cost to transport the system to orbit, and (3) that the radiator area is less for the two-phased system, which means the assembly labor costs will be lower.

The two systems compared are given by the pumped Freon-11 system of figure 2.4-6 and the pumped two-phased water heat transport system of figures 2.4-3 and 2.4-4.

The complexity factors were compared using the RCS PRICE modelling technique and the result came out $21.26M for the liquid and $16.08M for the two-phased, which results in $5.18M in favor of the two-phased system.

The transportation costs were calculated using $718 per pound to orbit and the difference in system weights. This resulted in $2.66M in favor of the two-phased system. The assembly costs were based on $77,000 per 24-hr day for astronaut time and the assessment that was used in the last study of 8-labor hours to assemble 100 square feet of radiator. This resulted in a $475,000 saving for the two-phased system.

The cost of advancing these technologies has been estimated at $0.8M for the heat exchanger program and $2.59M for advancing the two-phased water interior loop system (assuming use of shuttle test data for heat pipes rather than a complete independent

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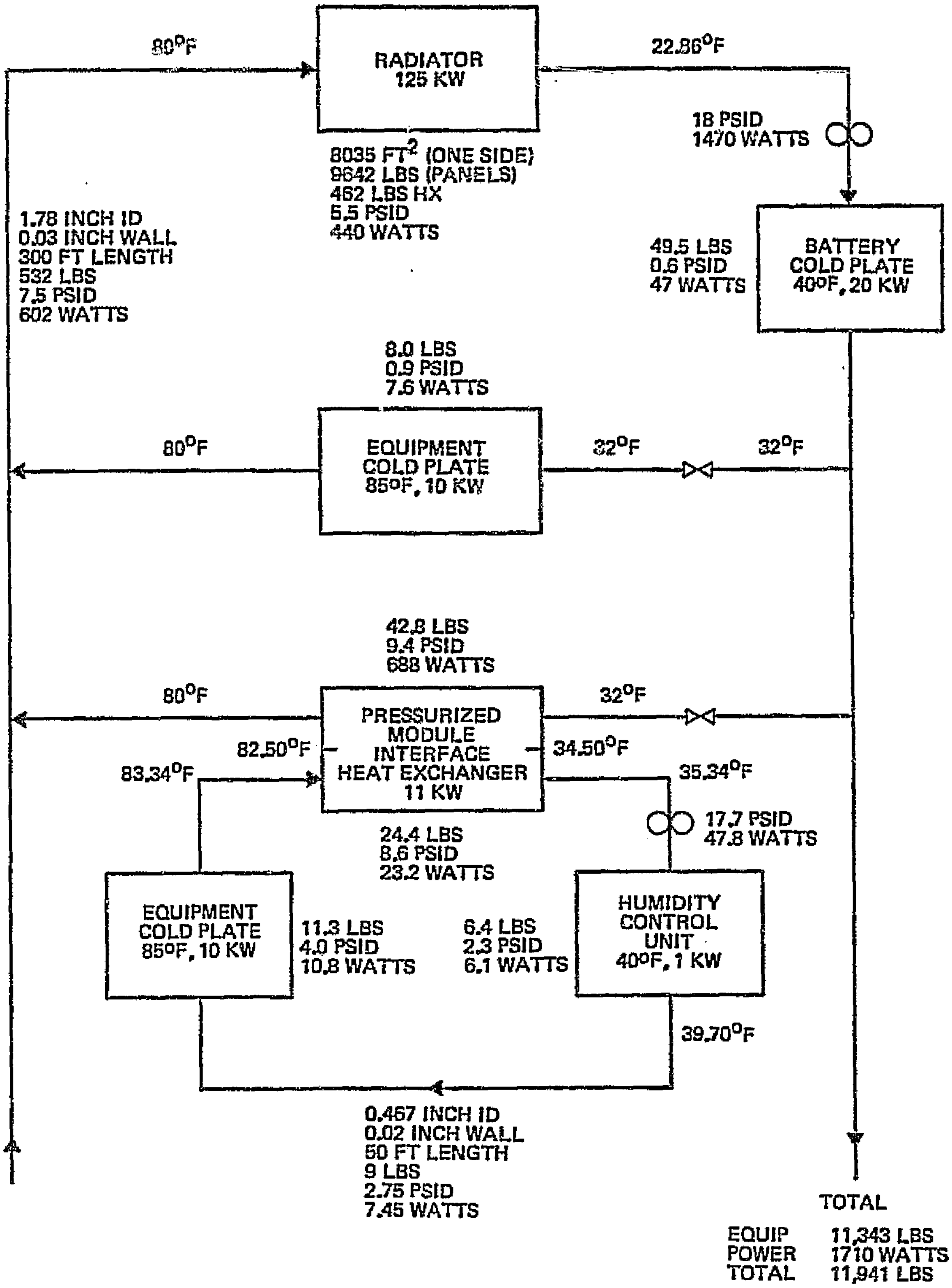

Figure 2.4-6 Pumped Liquid Freon-II System Schematic

flight test). Together these represent an expense for technology advancement for a two-phased heat transport system of $3.4M.

Using the above figures the cost over benefit ratio of advancing technologies to support the two-phased heat transport system is 0.41. This is based on the $3.4M advancement cost divided by $8.32M benefits.

2.4.5 Conclusions and Recommendations

The study results show that a pumped two-phase heat transport system provides some weight, power, and size reductions compared to a pumped liquid loop system. The two-phase system also offers greater flexibility in configuring the space station.

A capillary two-phase heat transport system offers the advantages of a pumped two-phase system with a relatively small weight increase. The capillary system does not need the pumps, valves, and controls needed for the pumped two phase system. Consequently a capillary system is, in principle, a more reliable system.

A two-phase water heat transport system for pressurized modules provides an additional weight savings when used with a two-phase main transport system. A capillary two-phase water system would provide increased reliability and reduced vibration and noise. Alternative pumping concepts for the pumped two-phase system were considered briefly. One concept uses an osmotic pump in place of the baseline mechanical pump. This concept provides pumping by osmotic pressure that causes solvent to flow through a semi-permeable membrane into a solution that flows to the evaporator. This concept requires auxiliary mechanical pumps to keep the solution from being diluted next to the membrane. The weight, reliability, and performance deficiencies of this concept eliminates it from serious consideration as an alternate pumping scheme. The other concept considered was an ion drag pump that produces fluid flow by creating ions in a corona discharge. The ions are accelerated in an electric field and impart momentum to the fluid. This scheme has the advantage of pumping with no moving parts. However, the pumping efficiency is only about 10%, high voltages are required, transport fluid must be a dielectric, and the corona discharge may have degrading effects on the fluid and electrode.

The results of this study showed that the weight of a two-phase heat transport system is approximately 1200/lbm less than that of a comparable single-phase system of identical

capacity. This 12% lower weight alone would probably not be sufficient justification for the selection of a two-phase system for the space station. The most compelling reasons for the choice of a two-phase transport system are (1) flexibility in locating heat loads and reconfiguring experiments, (2) modular growth of the station, and (3) stable temperature interface with cooling and heating loads over a wide range of operating conditions.

The two-phase system concept, however, has some inherent technical risks that will require expensive space flight testing to resolve. The developmental costs of the two-phase system would therefore be expected to be considerably greater than the cost of developing a single-phase system.

Additional information is needed before a sound decision can be made as to which thermal transport system should be selected for the initial space station. It is therefore recommended that a program be initiated to generate the necessary information to support the selection of a space station thermal transport system. A three step program is envisioned. In the first step, system requirements would be established. These requirements would stem from the definition of: (1) system loads such as experiments, equipment, etc., (2) planned space station evolutionary growth, and (3) space station mission planning.

Candidate single- and two-phase transport systems would be designed and optimized in the second program step. These systems would be developed for a baseline station and mission drawn from the step one requirements definition study. Dollar cost benefits of each transport concept would be quantified for all important system attributes including:

a. Mass.
b. Size.
c. Flexibility/growth.
d. Reliability.
e. Maintainability.
f. Constructability.
g. Operation costs.

In the third step, detailed plans for transport system development would be prepared. Developmental costs would then be predicted and a cost and benefit analysis performed to identify the best thermal transport system concept.

Regardless of the final selection of the thermal transport system concept for the space station, the potential benefits of the two-phase system warrant immediate technology development. Such developments are necessary to bring the level of technical maturity up to the point required for space station preliminary design. Because a pumped two-phase thermal bus system development program is currently in progress under NASA JSC contracts NAS9-16781 and NAS9-16782, it is recommended that emphasis should be placed on development of a two-phase transport loop suitable for thermal management within pressurized inhabited environments of the space station. The high performance fluids (ammonia or freon) envisioned for use in the main thermal transport bus cannot be used in inhabited areas due to their toxicity. Water would be the first choice for the working fluid in the internal transport loop. A two-phase design would provide the flexibility, modular growth capability, and isothermal interface characteristics desired for the overall thermal management system. Both mechanically pumped and capillary pumped loops should be investigated. Special emphasis should be placed on developing pump and heat exchanger technology that would benefit both the main thermal bus and internal transport loop concepts. In addition, capillary pumping for the main thermal transport system should be investigated because of the potential for increased reliability and reduced power, noise, and vibration by eliminating mechanical pumps.

2.4.6 Technology Advancement Plans

Recent developmental studies for long-life thermal control systems have identified some problem areas in the use of pumps on two-phase systems. This technology development plan has been derived to study and resolve those problems to bring pump technology to a state of readiness for a new start on the Space Station program. Figure 2.4-7 and table 2.4-2 provide schedule and resource planning information for the pump technology advancement.

Most two-phase thermal control concepts derived for application to the current modular manned space station have characterized two kinds of fluid loops. The bus loop most often uses a toxic working fluid like freon and ammonia because they have good thermal properties. However, for safety reasons, this loop is constrained to avoid exposure to the pressurized living spaces. For those areas, a water loop is suggested for heat transport. The device, which will exchange heat between the two systems, is the subject of the second thermal management technology plan and the schedule and resource plans are given by figure 2.4-8 and table 2.4-3 respectively.

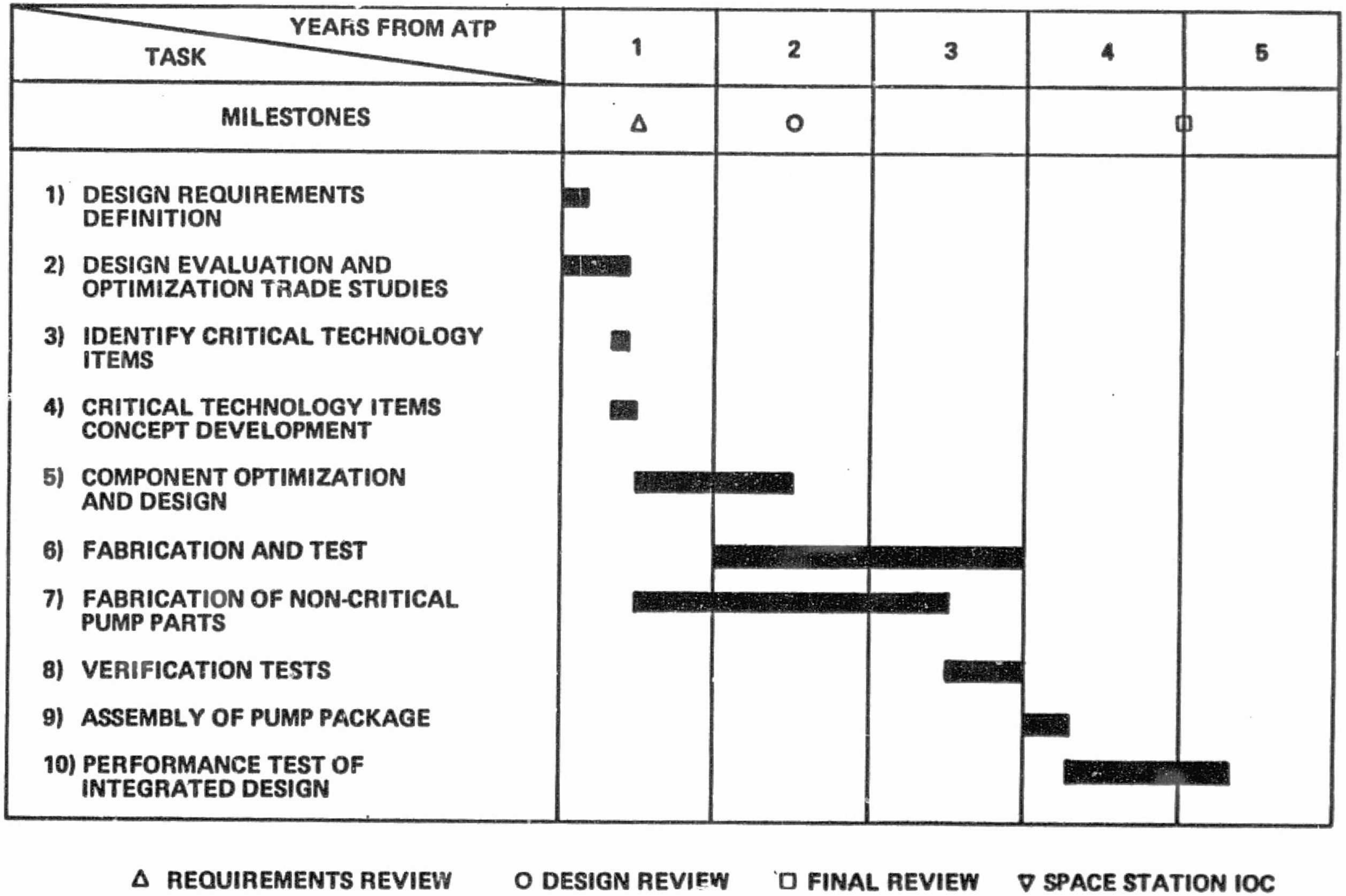

Figure 2.4-7 Schedule for Two-Phase Thermal System Pump Advancement Program

Table 2.4-2 Resources for Two-Phase Thermal System Pump Advancement Program

TASK \ YEARS FROM ATP	1	2	3	4	5	TOTAL
1) DESIGN REQUIREMENTS DEFINITION	16.7					16.7
2) DESIGN EVALUATION AND OPTIMIZATION TRADE STUDIES	62.5					62.5
3) IDENTIFY CRITICAL TECHNOLOGY ITEMS	4.2					4.2
4) CRITICAL TECHNOLOGY ITEMS CONCEPT DEVELOPMENT	18.8					18.8
5) COMPONENT OPTIMIZATION AND DESIGN	50					50
6) FABRICATION AND TEST		200	200			400
7) FABRICATION OF NON-CRITICAL PUMP PARTS	45	100	45			190
8) VERIFICATION TESTS			22.5			22.5
9) ASSEMBLY OF PUMP PACKAGE				35K		35
10) PERFORMANCE TEST OF INTEGRATED DESIGN				210	70	280
TOTAL	197.2	300	267.5	245	70	1079.7

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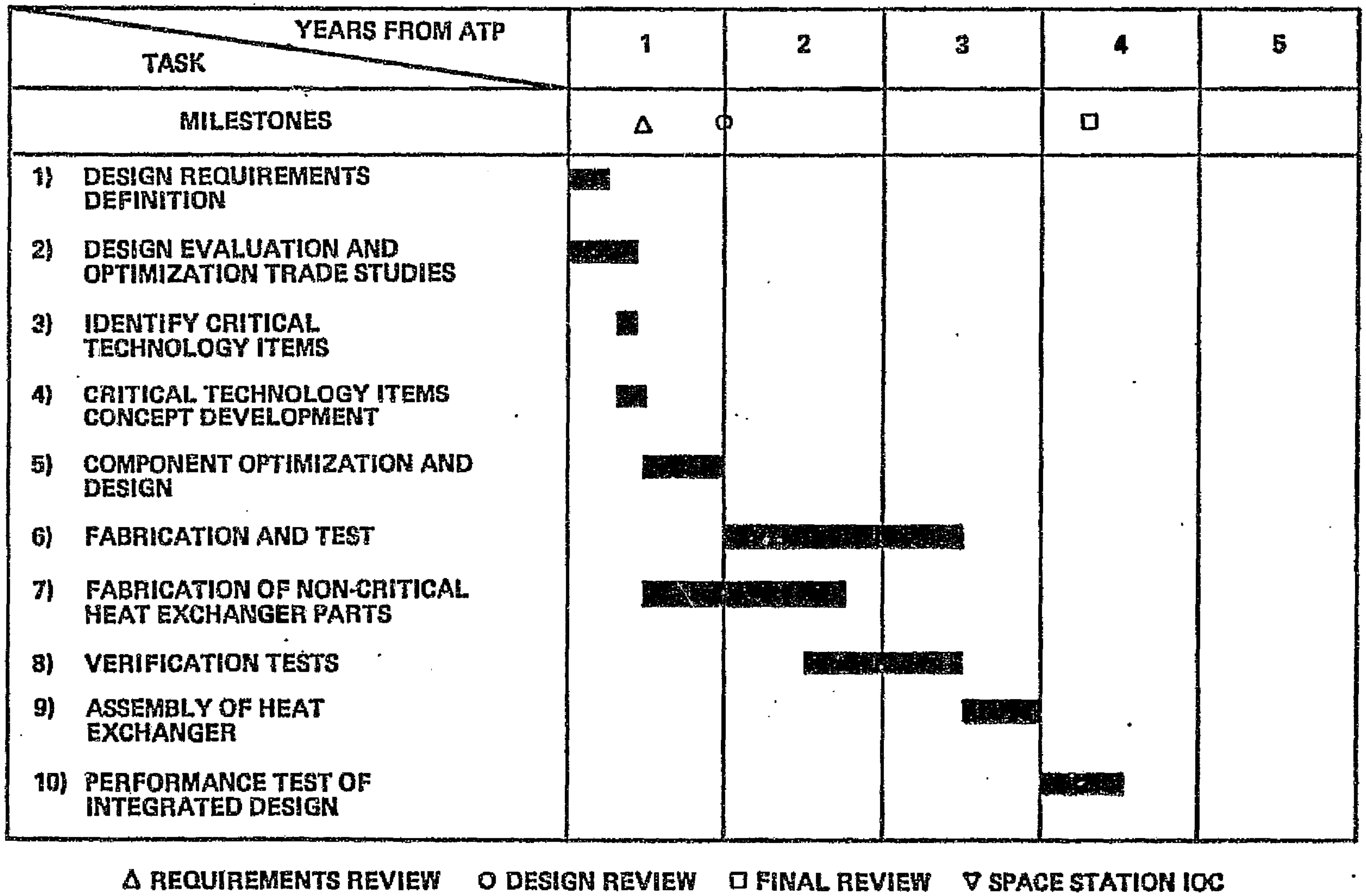

Figure 2.4-8 Schedule for Heat Exchanger Technology Advancement Program

Table 2.4-3 Resources for Heat Exchanger Technology Advancement Program

TASK \ YEARS FROM ATP	1	2	3	4	TOTAL
1) DESIGN REQUIREMENTS DEFINITION	16.7				16.7
2) DESIGN EVALUATION AND OPTIMIZATION TRADE STUDIES	62.5				62.5
3) IDENTIFY CRITICAL TECHNOLOGY ITEMS	4.2				4.2
4) CRITICAL TECHNOLOGY ITEMS CONCEPT DEVELOPMENT	18.8				18.8
5) COMPONENT OPTIMIZATION AND DESIGN	50				50
6) FABRICATION AND TEST		200	100		300
7) COMPONENT INTEGRATION INTO HEAT EXCHANGER					
8) FABRICATION OF NON-CRITICAL HEAT EXCHANGER PARTS	45	57.5			102.5
9) VERIFICATION TESTS		22.5	22.5		45
10) ASSEMBLY OF HEAT EXCHANGER			60		60
11) PERFORMANCE TEST OF INTEGRATED DESIGN				150	809.7
TOTAL	197.2	280	182.5	150	809.7

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The application of two-phase thermal management subsystem in pressurized modules of the space station configuration is the third technology for advancement in the thermal management area. Reliability and performance are key objectives for the development. Figures 2.4-9 and table 2.4-4 give the schedule and resource information respectively.

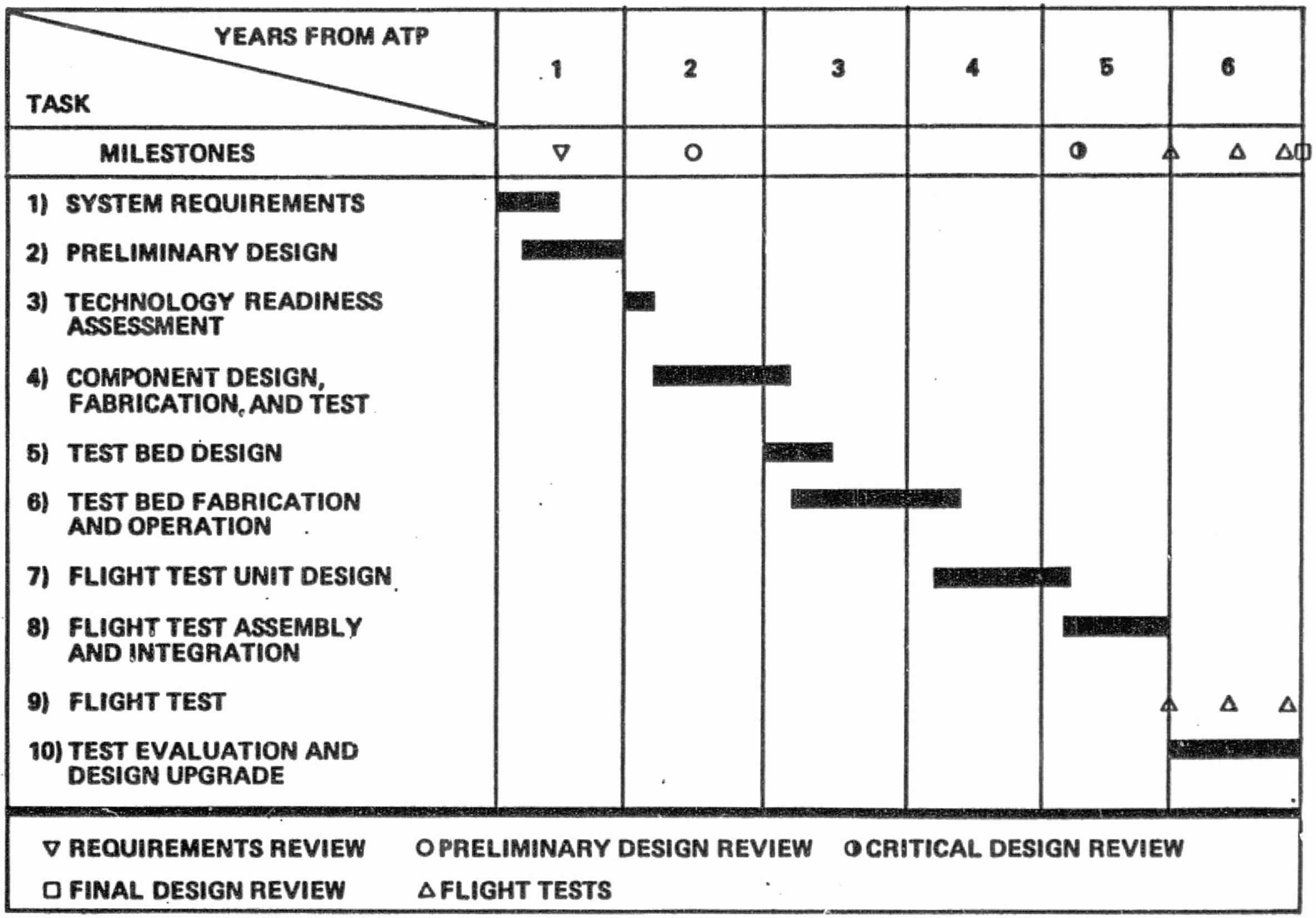

Figure 2.4-9 Schedule for Two-Phase Water Interior Loop Technology Advancement Program

Table 2.4-4 Resources for Two-Phase Water Interior Loop Technology Advancement Program

TASK / YEARS FROM ATP	1	2	3	4	TOTAL
FIGURES IN $1000 (1983)					
1) SYSTEM REQUIREMENTS	100				100
2) PRELIMINARY DESIGN	180				180
3) TECHNOLOGY READINESS ASSESSMENT		10			10
4) COMPONENT DESIGN, FAB, AND TEST		240	60		300
5) TEST BED DESIGN			200		200
6) TEST BED FABRICATION AND TEST			600	400	1000
7) TEST EVALUATION AND DESIGN UPGRADE					810
TOTAL	280	250	1070	1000	2600

NOTES:

HEAT EXCHANGER FROM OTHER TECHNOLOGY DEVELOPMENT PROGRAM ASSUMED TO BE USED IN TEST BED. DEVELOPMENT COSTS OF HEAT EXCHANGER MODEL NOT CHARGED TO THIS PROGRAM.

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2.5 INTEGRATION OF AUTOMATED HOUSEKEEPING

This study was conducted to characterize a system for integrating the automation of several housekeeping subsystems on an inhabited space station. This integration system will be a step toward meeting the autonomy/automation philosophy for the space station that was defined by the Concept Development Group (see table 2.5-1).

In a study completed in early 1983, the cost versus benefits of integrating the automation of several utilities producing subsystems on a space station was assessed. The results of this assessment indicate that the function of providing this integration could produce savings to the space station over a 10-year life of $184M. The same study indicated that a large part of the cost of such a system would be the software development and the probable use of expert systems technology. These cost figures were assessed as being about $9M. Because the system had not been described at a detailed level and because the cost and benefits were impressive, it was decided to conduct the current study to take a more detailed look at the functions of such a controller. The current study also produced a reassessment of the cost and benefits of the system and generated a more definitive identification of the applicability of expert systems to the process.

2.5.1 Approach

The objective of this study was to obtain a characterization of the integrating management controller to allow a better understanding of the benefits possible and the technology needed for implementing such a controller so that it will provide reliable, real-time management of the separate housekeeping controllers on a space station. To accomplish this objective, the results of the initial study were extended by a more detailed modeling of how a management type controller might be employed. The model was then examined to identify options in the implementation that better defined the benefits to be obtained from the integration process.

In performance of this task a system analysis was conducted to update the following list of functions to be performed by each of the three automatic housekeeping subsystem controllers:

Table 2.5-1. Space Station Autonomy/Automation Philosophy

Subsystem/system monitoring and control will be performed onboard.
Systems monitoring and control will be automated.
Fault detection and isolation will be an automated function for all subsystems.
Redundancy management including reconfiguration will be performed automatically onboard.
Reverification of systems/subsystems elements will be performed automatically on board.
Operations planning and scheduling will be performed onboard.
The degree of automation will increase as the space station grows and technology becomes available.
Collection and analysis of trend data will be automated.
The space station platform shall have the same degree of automation onboard as the manned base.

Table 2.5-2: Functions For Housekeeping Controllers

Electrical Power	Thermal	Life Support
Control voltage at power user outlets.	Control temperature to set points within cabins.	Control oxygen and nitrogen supplied to cabin.
Control power levels at power user outlets.	Control temperature at heat exchangers for specific equipment items.	Control contamination level in cabin air.
Switch sources based on sensed status of sources	Control humidity of cabin atmosphere.	Control quality of potable and wash water. Removal of CO_2 from cabin air.

The above table indicates the starting point on independent control functions within each of the three housekeeping subsystems on the space station considered in this study. These functions are those that relate to maintaining the environment on the space station for the crew and for the mission-peculiar equipment. The list was expanded for models of the three subsystems to the level of detail where the control parameters would be sensed.

A systems analysis was performed to develop a concept for integrating the control of the three housekeeping functions and to identify the control parameters.

Based on the interactions identified, functions were defined for the integrating controller. Functional block diagrams were then developed along with functional descriptions of each of those defined.

Because various mode shifts would be selected and implemented by an integrating controller, it was necessary to identify the mode shifts and to assess the sequencing of the action. The scenarios for operation of an integrating controller were conceptualized in this subtask by a systems analysis approach.

A systems analysis was then conducted for an integrating controller for automated housekeeping functions in cooperation with data management specialists to identify hardware and software elements of a concept and to isolate technologies to be considered for advancement in order to implement the concepts. The use of artificial intelligence in the form of expert systems was explored to implement the flexibility and tolerance for change needed in this integrating controller.

2.5.2 Technical Discussion

The automation of three subsystems on an inhabited space station was investigated to identify the functions to be performed and the sensing that would be needed. The three subsystems were electrical power, life support, and thermal management. The automation being considered is that which would be used internal to each of these subsystems to enable them to perform their functions automatically. The integration of these automated systems deals with interactions between them, with outside factors which affect them all, or with trends that involve more than one subsystem.

Tables 2.5-3 through 2.5-5 show the results of analysis conducted of these subsystem concepts and lists the functions and sensed quantities for the automations identified.

The functions and sensed quantities in these tables were then used to construct an interface tabulation (see figure 2.5-1) to identify when interactions between the automated subsystems could exist and where outside events could influence the overall operation. These identifications lead to the definition of functions for the integrating controller.

The integrating controller is a concept that is intended to provide management level control of automated utilities subsystems on a manned space station. Initially this controller would be largely an advisory service for the astronauts. As such, it would tend to replace the advisory service that has been provided by mission control with a more autonomous interactive system that the astronauts can use on board. Because there will be actions that will be repetitive and bothersome to the astronauts, it is a worthy goal to seek a fully automatic integrating controller for some functions.

Based on the interactions shown by figure 2.5-1, it is clear that the three subsystems affect each other significantly and that there are outside factors that affect them all. The functions performed by an integrating controller would then deal with those interactions, as shown by figure 2.5-2. Inspection of these indicate the following:

1. Electrical power load management is needed because both thermal and life support are heavy power users and reduction of their usage to balance loads needs to consider their interacting functions.

TABLE 2.5-3

ELECTRICAL POWER SUBSYSTEM AUTOMATION

Functions

- Control solar array orientation
- Control of solar array selection - segment selections
- Regulation of solar array output voltage - shunt regulation
- Control of battery charge-discharge processes
- Battery selections - cell selections
- Load sharing control of regulators
- Shunting for under use control
- Redundancy Management within the electrical power system

Sensed Quantities

- Solar array temperatures
- Solar array positions
- Solar array voltages by sections of the array
- Battery cell voltages
- Battery cell temperatures
- Battery cell pressures
- Battery charge voltage
- dc/dc converter line voltage
- Transformer coupled converter output voltage
- Series resonant inverter (dc/ac) output voltage
- Series resonant inverter fuse status
- Magnetic latching relay position
- Cable temperature

TABLE 2.5-4

LIFE SUPPORT SUBSYSTEM AUTOMATION

O_2 Generation

Functions

- Control of the flow of water to the electrolysis units
  - Valve operation
  - Pump operation
- Control of electrolysis current
- Control of the flow of H_2 away from the unit
  - Valve operation
- Control of the flow of water away from the unit
  - Valve operation
  - Pump operation
- Control of the flow of oxygen away from the unit
  - Valve operation
- Redundancy management within the O_2 generator
  - Detection of failure
    - Abnormal values of several quantities
  - Selection of redundant elements: generators/pumps/valves

Sensed Quantities

- Partial pressure of cabin O_2
- Flow rate of input water
- Pressure of H_2 at output
- Flow rate of water at output
- Pressure of O_2 in storage at output
- Selected set point condition
- Status of valves, pumps, generators and storage units

TABLE 2.5-4 (Continued)

LIFE SUPPORT SUBSYSTEM AUTOMATION

N_2 Supply

Functions

- o Control of the flow of N_2 from storage
  - o Valve operation
- o Redundancy management functions within the N_2 supply
  - o Detection of failures
    - o Abnormal values of several quantities
  - o Selection of redundant valves

Sensed Quantities

- o Cabin pressure
- o Pressure of N_2 storage tanks
- o Selected set point
- o Status of valves and storage tanks

CO_2 Removal

Functions

- o Position of by-pass valves to control air flow to beds
- o Position of by-pass valves to isolate beds for desorption from the cabin
- o Control of electric heaters to create steam to flow through beds being desorbed
- o Control of valves to direct CO_2 to the reduction system from the beds being desorbed
- o Control of valves to provide hygenic water for steam into desorbed beds
- o Redundancy management
  - o Detection of abnormal sensed values
  - o Selection of redundant elements: fans, by-pass valves, beds, and steam generators

TABLE 2.5-4 (Continued)

LIFE SUPPORT SUBSYSTEM AUTOMATION

Sensed Quantities

- Partial pressure of cabin CO_2
- Flow rate of water at input to steam generator
- Pressure of CO_2 in accumulator at output
- Temperature of steam in steam generator
- Flow rates at desorbed bed
- Status of beds being used for absorption and being desorbed
- Status of valves and fans
- Selected set point

CO_2 Reduction

Functions

- Mixing of H_2 and CO_2
- Flow of mixed CO_2 and H_2 through filter to the reduction unit
- Pump and valve control for water accumulator at reduction unit output
- Redundance management within the CO_2 reduction unit
  - Selection of redundant elements: reduction unit, valves, and accumulator
  - Failure detection based on abnormal sensed values
- Cooling for unit

Sensed Quantities

- Flow and pressure of gases at input
- Temperature of unit
- Flow and pressure of gases at output of unit
- Flow of water to accumulator
- Capacity filled with water in accumulator
- Flow of water out of accumulators
- Status of valves and accumulators

TABLE 2.5-4 (Continued)

LIFE SUPPORT SUBSYSTEM AUTOMATION

Trace Contamination Control (TCC)

Functions

- o By-pass valves to control air flow through beds
- o Annunciation of below normal bed status
- o Control of power to electric heaters
- o Redundancy management within the trace contamination control system
  - o Failure detection based on abnormal sensed values
  - o Selection of redundant elements: alternate fans, paths through beds, and oxidizer

Sensed Quantities

- o Level of contamination
- o Temperature of oxidizer
- o Flow through units
- o Status of fans, valves, oxidizer heater and beds
- o Selected set point

Potable Water Process

Functions

- o Control of water flow to post-treat
  - o valves
  - o pump
- o Control of cycling in post-treat and Water Quality Monitor (WQM)
  - o valves
  - o pumps
  - o WQM processes
- o Control of flow to selected storage tank
- o Control of iodine addition in storage tank testing process
- o Control of overflow to hygienic water
- o Control of water heater
- o Control of use flow out of storage tanks

TABLE 2.5-4 (Continued)

LIFE SUPPORT SUBSYSTEM AUTOMATION

Functions (Cont)

- o Redundancy management with the potable water processor system
  - o Failure detect
  - o Seclection of redundant elements: accumulators, water quality monitors, (WQM), tanks, valves, and beds

Sensed Quantities

- o Capacity filled in accumulators
- o Measured contaminants in WQM
- o Capacity filled in storage, test, use tanks
- o Iodine level in storage tank test processing
- o Post treat valve and bed status
- o Water temperatures in system
- o Storage tank valve status
- o Water flow rates in system

Hygenic Water Process

Functions

- o Control of pre-treat pumping
- o Control of pre-treat biopal VRG 20 addition
- o Control of pumping and valving into the vapor-compression distillation (VCD) unit
- o Control of compression in VCD
- o Control of heating in VCD
- o Control of conductivity testing of VCD condensate and valving for output
- o Control of post-treat valving and pumping
- o Control of WQM processes
- o Control of flow to fill-use tanks
- o Control of flow out of fill-use tank

TABLE 2.5-4 (Continued)

LIFE SUPPORT SUBSYSTEM AUTOMATION

Functions (Cont)

- o Redundancy management within the hygenic water processor system
  - o Failure detect
  - o Select redundant elements: WQM, VCD, valves, fill tanks, pumps and heaters

Sensed Quantities

- o PH level in pre-treat
- o Flows in pre-treat
- o Waste holding tank capacity filled
- o Valve status indicators
- o Waste tank capacity filled
- o Sludge tank capacity filled
- o Flows into VCD
- o Pressure in VCD
- o Temperature in VCD
- o Conductivity of VCD condensate
- o Flow of condensate from VCD
- o Measured contaminants in WQM
- o Post treat valve and bed status
- o Flow rates in post treat and storage
- o Storage tank valve status
- o Capacity filled in storage tanks
- o Capacity filled in accumulators in system

Wash Water Process

Functions

- o Control of pumping to work holding tank
- o Control of pumping and valving to hyper-filtration process

TABLE 2.5-4 (Continued)

LIFE SUPPORT SUBSYSTEM AUTOMATION

Functions (Cont)

- Control of heating in hyper-filtration process
- Control of valving and pumping from the hyper-filtration process
- Control of the addition of sodium hypochlorite in post-treat
- Control of the addition of iodine in post-treat
- Control of pumping and valving for post-treat
- Control of pumping and valving for storage of wash water
- Redundancy management within the wash water processor system
  - Failure detection
  - Selection of redundant elements: pumps, valves, hyper-filtration units, and tanks

Sensed Quantities

- Flows to and from holding tank
- Flows to and from the hyper-filtration processor
- Temperature of hyper-filtration processor
- Capacity filled in holding tank
- Capacity filled in hyper-filtration process
- Measured contaminants in WQM
- Post-treat valve and bed status
- Flows for post-treat and to storage
- Storage tank valve status
- Capacity filled in storage tanks
- Quantity of iodine and sodium hypochlorite available for use
- Capacity filled in sludge tank

TABLE 2.5-5

THERMAL CONTROL AUTOMATION

Functions

- Control of cabin air flow through heaters
- Control of heaters
- Control of heat exchanger condensate flow to separators
- Control of water flow out of separators
- Control of positions of steerable radiators or selections of selectable radiators
- Control of coolant flow - valve positions or pump speeds
- Redundancy management within the thermal control system
  - Sensed failures from abnormal sensor values
  - Selection of redundant elements: fans, heaters, heat exchanges, separators, pumps, and valves

Sensed Quantities

- Temperature of cabin air
- Humidity of cabin air
- Input air flow to heater
- Condensate flow at heat exchanger
- Water flow out of separators
- Air flow out of separators
- Heater temperature
- Set point status
- Equipment status
- Position and rate information for steerable radiater servos
- Valve positions
- Pump speeds

FIGURE 2.5-1

TABULATION OF INTERFACES BETWEEN HOUSEKEEPING FUNCTIONS

INTERFACE BETWEEN ELECTRICAL AND THERMAL

- o Battery cell temperatures
- o Cable temperature
- o Control of heaters (power usage)
- o Shunting of power (generates thermal load)

INTERFACE BETWEEN ELECTRICAL AND LIFE SUPPORT

- o Control of electrolysis current (power usage)
- o Control of electric heaters to create steam to flow through beds being desorbed (power usage)
- o Control of power to Trace Contamination Control Heaters (power usage)
- o Control of heating in VCD (power usage)
- o Control of heating in hyper-filtration process (power usage)
- o Control of water heaters (power usage)

INTERFACE BETWEEN THERMAL AND LIFE SUPPORT

- o Temperature of cabin air
- o Humidity of cabin air

air to life support

- o Water flow out of separators (water to life support)
- o Air flow out of separators (air to life support)

OUTSIDE FACTORS WHICH EFFECT HOUSEKEEPING

- o Lightside/Darkside
  - o Electrical power solar arrays
  - o Thermal radiators
  - o Outside lighting
  - o EVA constraint
- o Crew size and level of activity
  - o Life support load
  - o Load on electrical power
  - o Energy input to thermal
  - o Moisture input to thermal
  - o Distribution of life support materials, power loads, and thermal loads
- o Compliment of Experiments
  - o Load on electrical power
  - o Load on life support materials
  - o Constraint on dumping of waste
  - o Thermal/humidity input
  - o Distribution of life support materials, power loads, and thermal loads
- o Shuttle Docked or Away
  - o Air mixing between shuttle and station
  - o Possible extra crew
  - o Possible power sharing considerations
  - o Possible thermal sharing considerations
- o EVA or not
  - o Extra load on life support before and after
  - o Less load during
- o Maintenance
  - o System shutdowns while need for functions continues
  - o Effect of maintenance on variations in performance of systems
  - o Effect of maintenance on crew activity - EVA

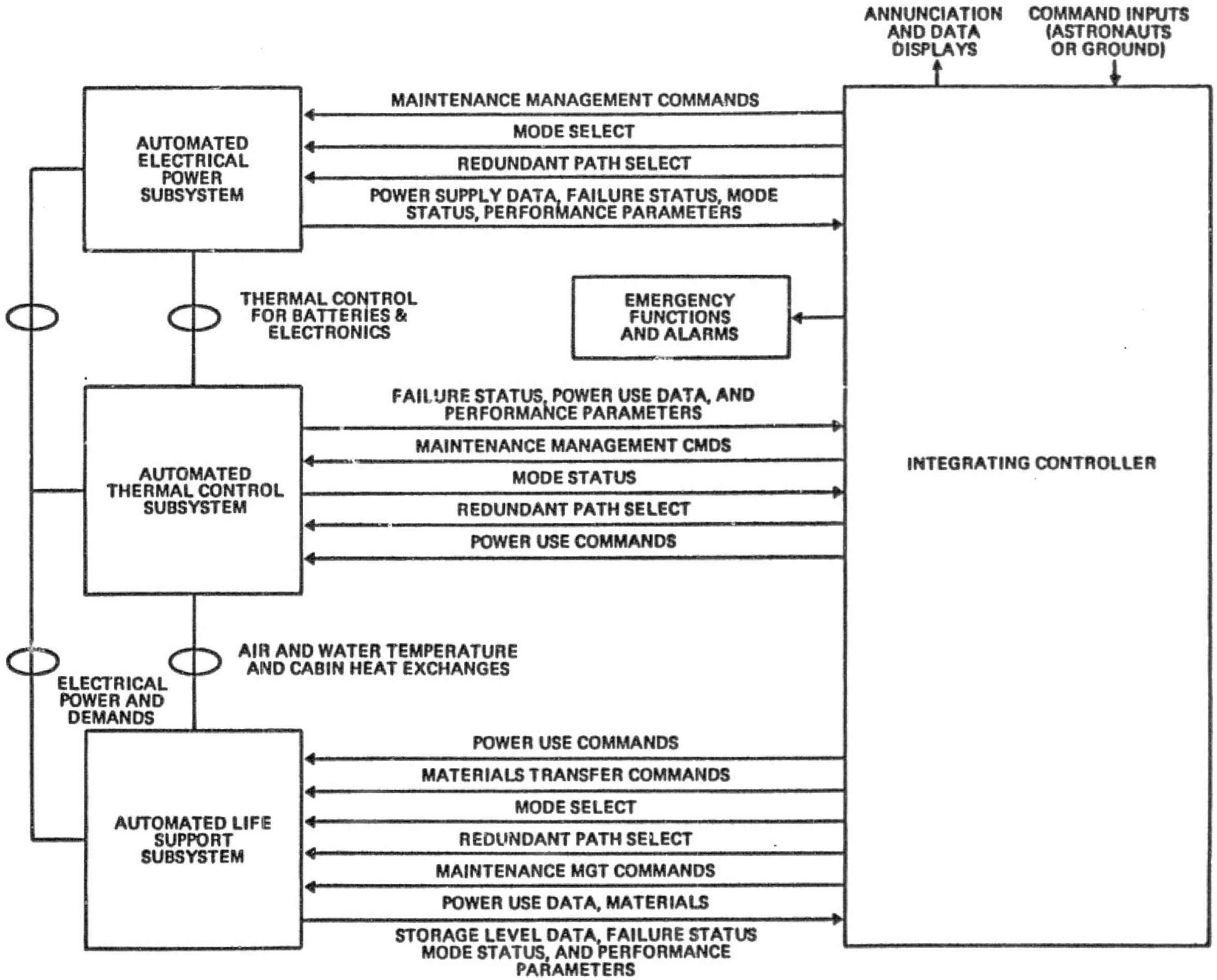

Figure 2.5-2 Interfaces Between an Integrating Controller and Automated Housekeeping Subsystems

2. Materials transfer management is needed because outside factors affect the location of needs as well as the location of the availability of life support materials around the space station. In many cases transfers need to be considered against scheduled events and against dumping constraints as well as impacts on power and thermal loading.

3. Intersubsystem failure isolation is needed because failure diagnosis outside of subsystem boundaries will have to be conducted in order to trace the cause through the interacting functions. For example, an apparent failure of the separator in the thermal or humidity control system could be caused by an actual failure in the Water Quality Monitor (WQM) in the life support which is producing a backup into the accumulator receiving the condensate from the separators. In this case failure isolation within a subsystem would not be sufficient to find the problem.

4. Intersubsystem redundant path selection is needed because selection of redundant paths in response to failures or maintenance shutdown will have to consider the impact on interacting subsystems.

5. Maintenance schedule management is an integrated function since changes to the timing of maintenance actions for one subsystem can have affects on the operation and maintenance of other subsystems. This is because maintenance may cause temporary shutdowns and may result in changes in performance of the maintained subsystem which affect others.

6. Start-up integration is needed to control the interdependent sequencing of bringing subsystems on line so that outputs are available before the need is created.

Figures 2.5-3 thru 2.5-8 give functional diagrams for these six functions.

Scenarios, for initialization of a space station system and for a shift in life support modes on a space station, were developed to describe the operating environment for the integrating controller.

An initialization scenario is to describe events that might occur as a space station module is initialized for habitation by the crew. It is assumed that the shuttle is attached and that the crew relies on the shuttle systems to support the initial EVA. As

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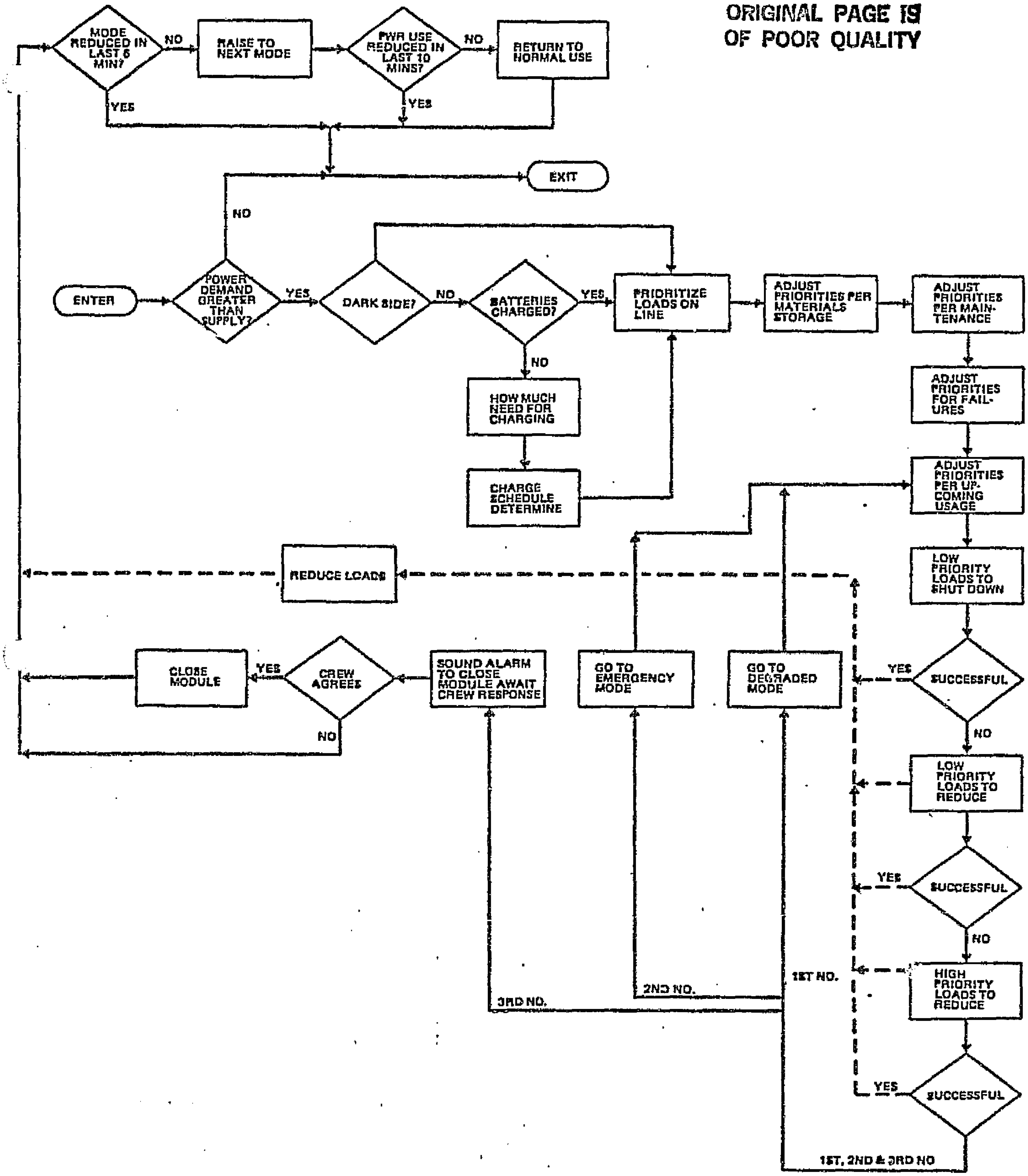

Figure 2.5-3. Functional Block Diagram for Electrical Power Load Management by an Integrating Controller

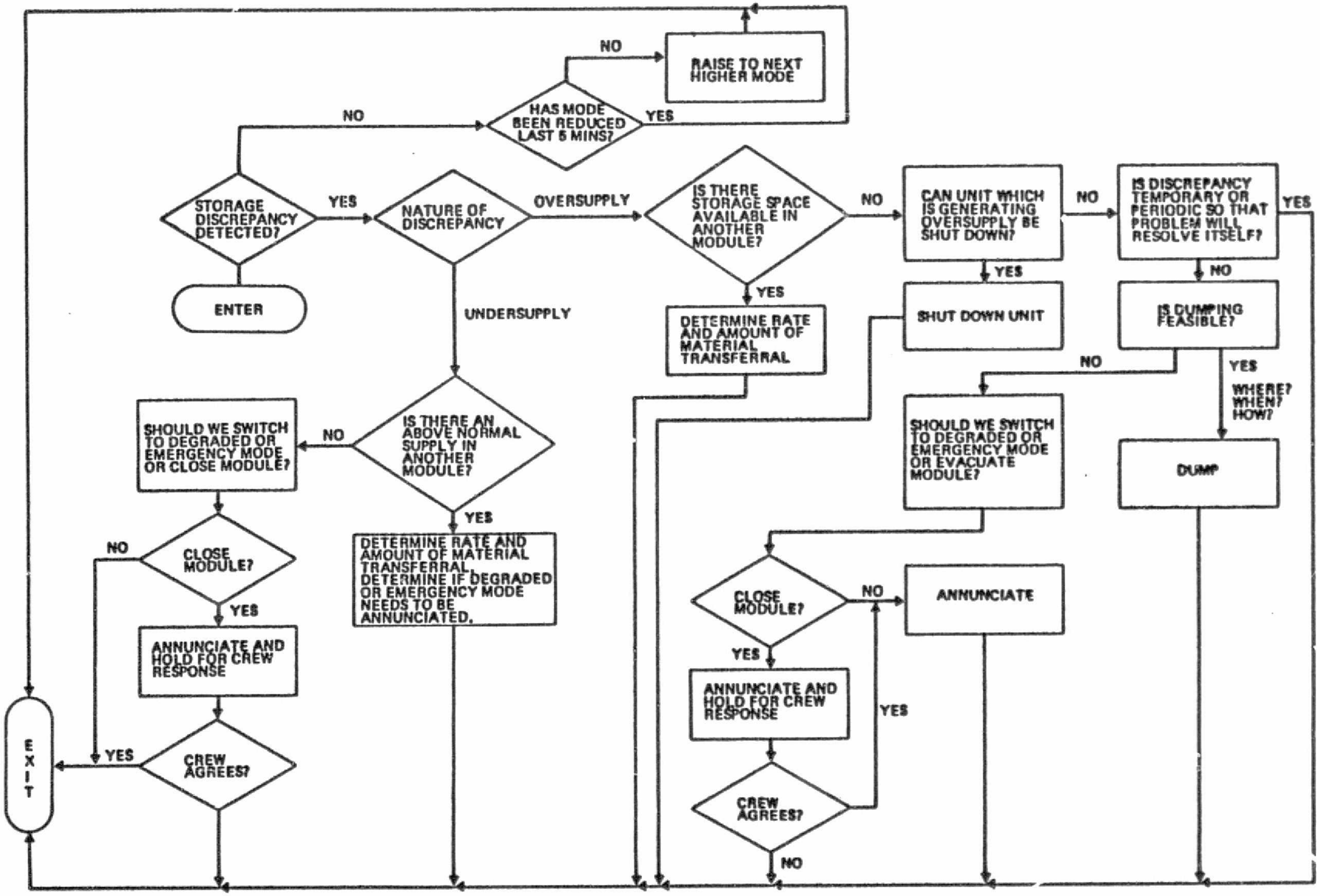

Figure 2.5-4 Functional Block Diagram for Materials Transfer Management by an Integrating Controller

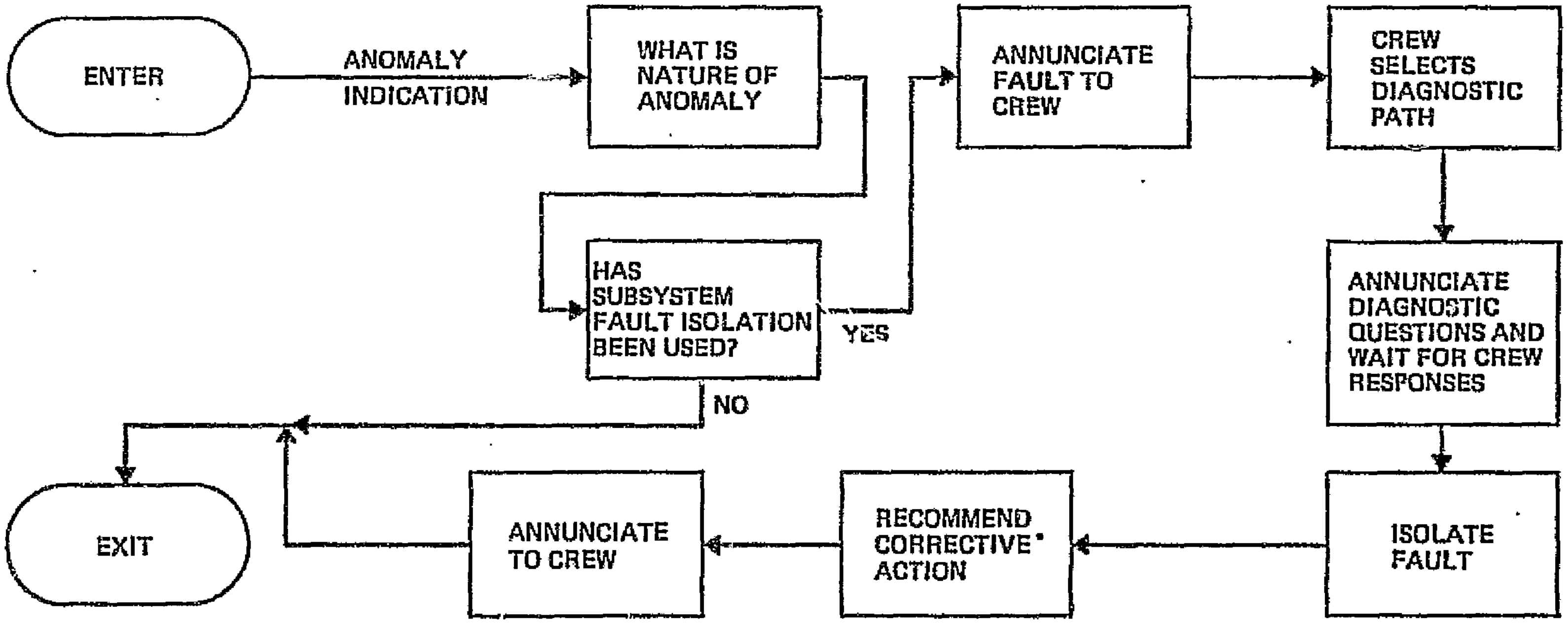

Figure 2.5-5 Functional Block Diagram for Inter-Subsystem Failure Isolation Using Integrating Controller

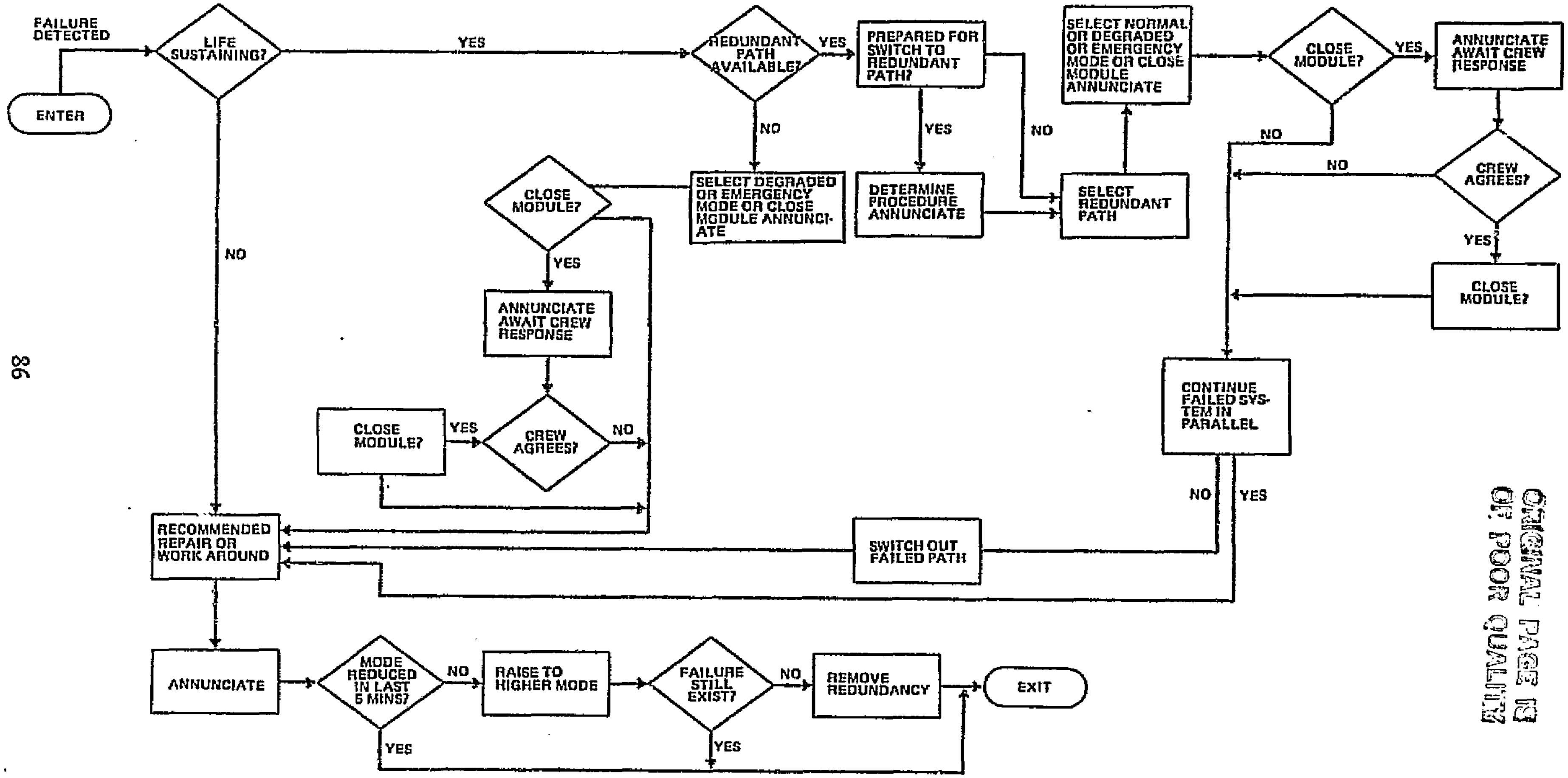

Figure 2.5-6. Functional Block Diagram for Inter-subsystem Redundant Path Selection by an Integrating Controller

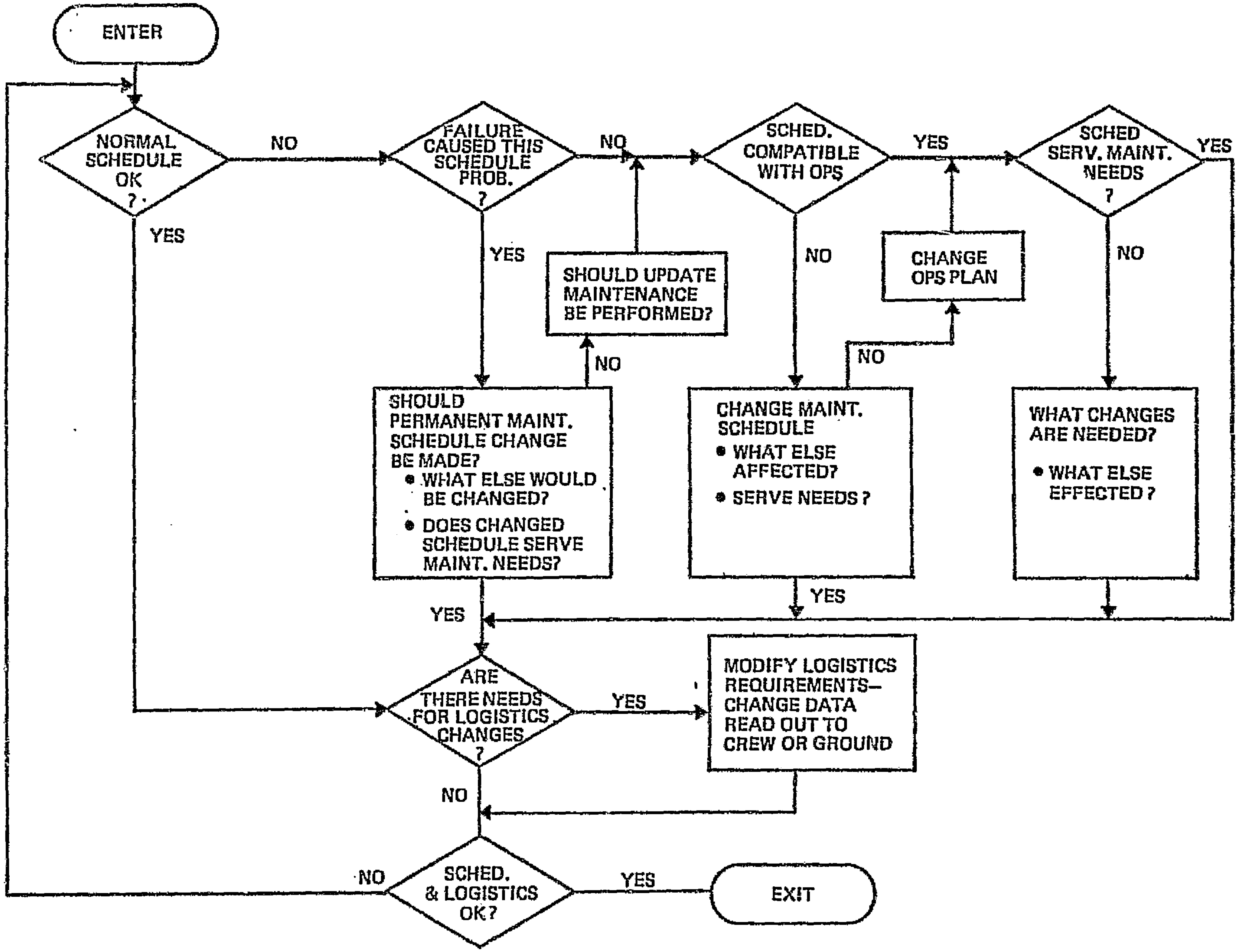

Figure 2.5-7 Functional Block Diagram for Maintenance Schedule Management by an Integrating Controller

C-2.

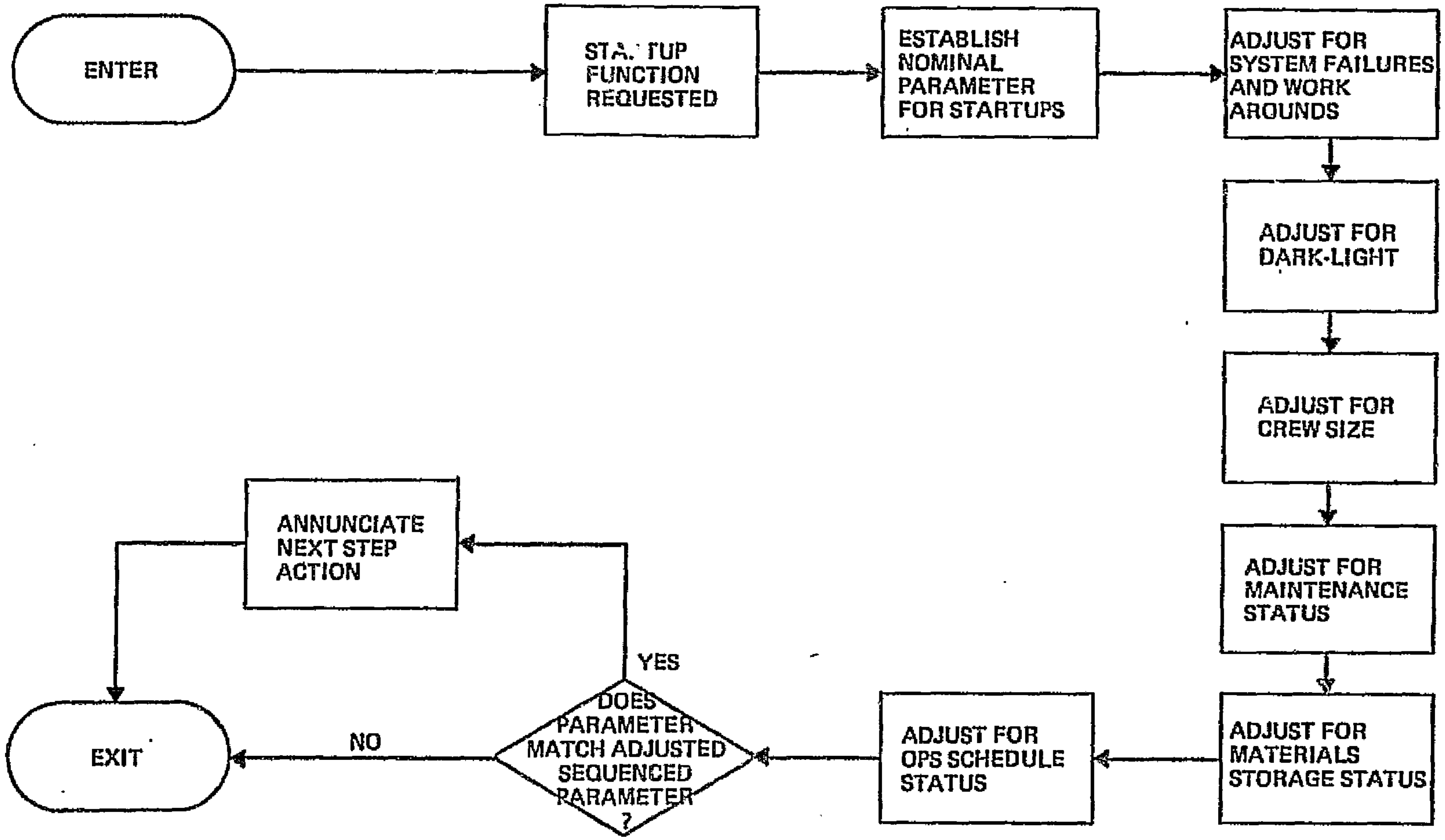

Figure 2.5-8 Functional Block Diagram for Startup Integration by an Integrating Controller

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can be seen, no attempt is made to work out the specific number of orbits for this process. The initialization crew will start out using EVA and then will go to shirt sleeves after orbit L. The initialization crew would be two or possibly three astronauts and would be joined by the remainder of the crew after orbit W.

		Orbit
(1)	Close cabins and establish initial atmosphere	N
(2)	Cabin power available	N + M
(3)	Cabin heat exchangers	N+M+1 = L
(4)	Cabin Trace Contamination Control (TCC) on	N+M+1 = L
(5)	Cabin dehumidifiers on	N+M+1 = L
(6)	O_2 generators on	L+R = Z
(7)	N_2 supply opened	L+R = Z
(8)	Cabin air heaters on	L+R = Z
(9)	CO_2 removal on	Z+1
(10)	CO_2 reduction on	Z+2
(11)	Crew begins cabin occupancy	Z+S = W
(12)	Potable water loop on	Z+S = W
(13)	Hygienic water loop on	Z+S = W
(14)	Wash water loop on	Z+S = W

The mode shift sequence is the result of a change in the life support subsystem operating mode between the nominal, degraded, or emergency set points. Again this is a conceptual sequence of events to be described more specifically after the space station design becomes more defined.

1. Mode change selected either by crew or the integrating controller.
2. The integrating controller then adjusts control limits for each automatic system reference to correspond with selected mode.
3. System configured for mode shift as necessary by commands from the integrating controller.
   a. Materials transfer
   b. Power Adjustments
   c. Path Selection
4. Maintenance schedule adjusted as needed.
5. Annunciation to crew.

6. Implement mode shift.

An integrating controller will consist of onboard central and distributed processors that will initially be supported by an earth-based central data processing facility, which can be used by employing the telemetry link. The processing functions will be largely in the onboard central processor for all decision making and command generating. The distributed processors will be used for data collection and command execution functions. The earth bound facility will be used for some off line comparisons and determinations, especially for failure diagnostics and logistics control. Figure 2.5-9 shows a typical processor hierarchy and data path connection concept for a integrating controller. The diagram indicates where the functions are in the central processor and where they are distributed.

The following functions of the integrating controller are indicated to be definite candidates for some expert systems processing.

1. Electrical power load management - the MSFC has a study which is being conducted by Martin Marietta and the indication from that study is that expert systems apply to this function.
2. Redundant path selection - work is being done to apply expert systems to this problem for nuclear power plants.
3. Maintenance schedule management - this general area is considered to be a promising application of expert systems.

All of the other functions were considered by artificial intelligence specialists to be good candidates for at least partial application of expert systems.

Any estimate of the size of the expert systems parts of an integrating controller is constrained by the following:

1. The preferred current method of developing an expert system is to use an expert system language analogous to a programming language for conventional automation. The number of statements in a conventional program can vary drastically depending on the language. In the case of expert systems, there is probably at least a 3:1 variation in number of rules depending upon the language used.

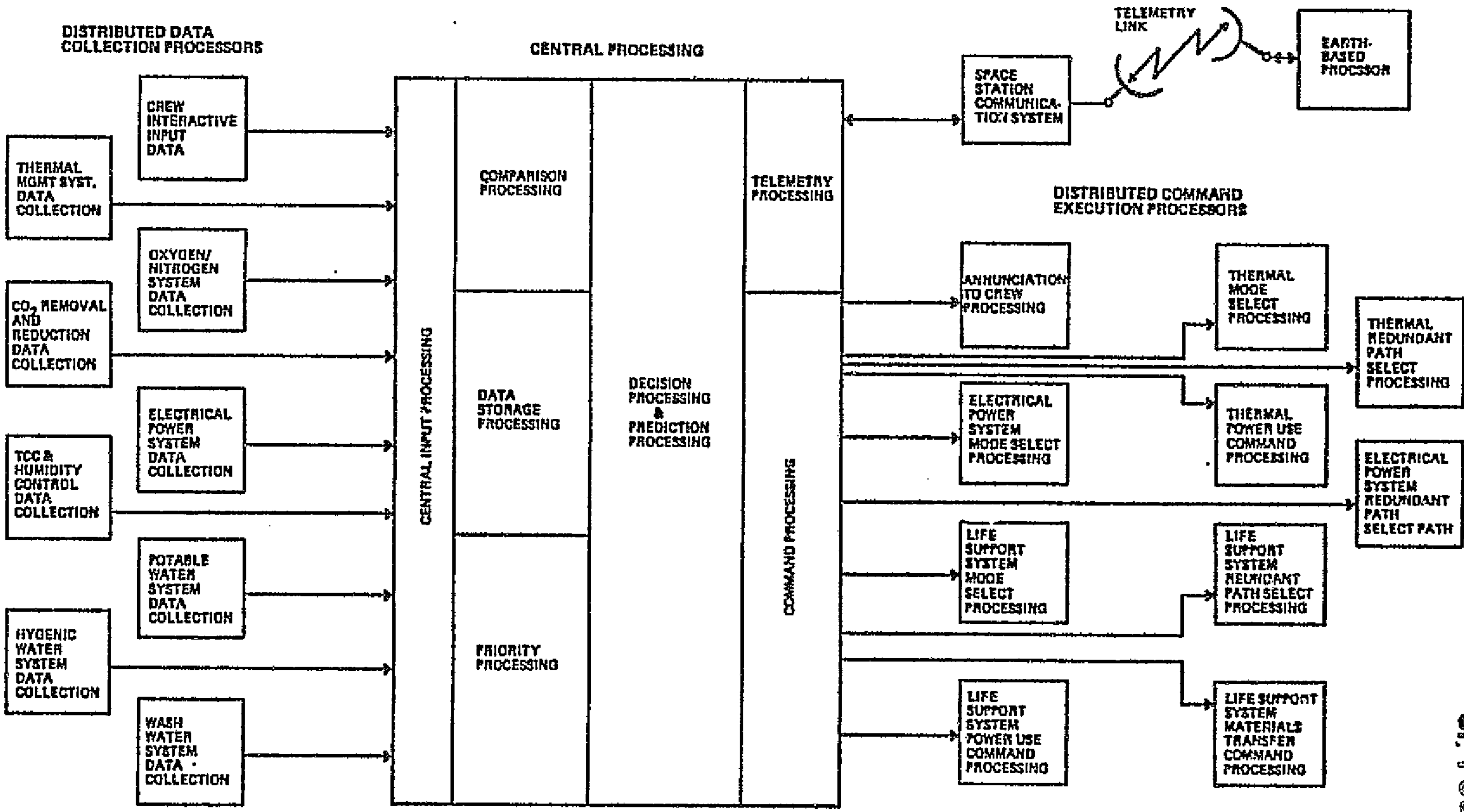

Figure 2.5-9 Processing Functional Diagram of Integrating Controller for Automated Housekeeping

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2. Expert systems do not have to be developed using rules. Rules are a knowledge representation technique. There are other ways of representing knowledge including:

   - Logic
   - Networks
   - Frames
   - Hybrid

This is one reason why an integrating controller would involve several expert systems for its different types of functions.

Given the above caveats, it was estimated that as an example, the intersubsystem failure isolation function expert system would involve from 1,000-3,000 rules, and in that case using rules for estimating is probably a good way to go.

Factors to consider when describing whether to use space borne or ground based computers for the integrating controller include:

1. Criticality—will the astronauts be threatened if access to the integrating controller is interrupted?
2. Resource usage—does the integrating controller use an excessive amount of space borne computer resources?
3. Data bandwidth—does the integrating controller process so much data that transmitting it to earth would jug up the communications channels?

Because of the criticality of the failure isolation function and redundant path selection function, they would be high priorities for space borne implementation. Maintenance scheduling could probably be ground based at least in the early stages of the space station.

In order to estimate the space borne computational capability required, several assumptions will be made:

1. The expert systems used will be programmed for the onboard system using the LISP programming language. (LISP is a heavy user of resources).

2. The space station has a distributed processing system consisting of general purpose as well as special purpose processors.
3. General purpose processors are machines with 32-bit CPUs, 2 MIPS throughput and 1 MB of memory.
4. Mass storage will be available to store expert systems rules when not actively being processed.

Based on these assumptions, it is estimated that an expert system implementation would require a general purpose processor for active processing of each expert system function of the type exemplified by intersubsystem failure isolation system.

Any large expert system might require a special purpose processor, and unless the function was extremely critical for crew safety, it would not be space borne.

To estimate the effort needed to develop an expert system a single function such as the failure isolation is estimated to require at least 5-10 man-years of effort. Assuming one expert system per function, 30-60 man-years of effort would be required. (Currently, 5 man-years seems to be the quickest any expert system can be developed).

All of this indicates that expert systems have a role to play in the integrating controller concept, but that they are, when based on current technology, heavy users of computational resources and development effort.

2.5.3 Concept Trades

The results of the concept characterization studies for an integrating controller are basically the definitions of functions to be performed by such a controller, and concepts for processing of those functions onboard the space station or on the ground using distributed as well as centralized architecture. This section discusses the comparisons conducted with respect to these characterizations and the identification of technology advancements needed.

Figure 2.5-10 gives a trade of the functions of the integrating controller against five fairly nonquantifiable criteria.

TECHNOLOGY DISCIPLINE:	INTEGRATION OF AUTOMATED HOUSEKEEPING
TECHNOLOGY ADVANCEMENT GOAL:	TO REDUCE COST OF MAINTAINING THE HOUSEKEEPING FUNCTIONS ON A SPACE STATION WHILE ENHANCING CREW SAFETY AND COMFORT.
SPECIFIC TRADE:	COMPARE SIX FUNCTIONS OF AN INTEGRATING CONTROLLER AGAINST CRITERIA OF: USE FREQUENCY, INTERACTIVE SUPPORT, ESSENTIAL FOR SAFETY, DETERMINISTIC PROCESSING AND DURABILITY.

TRADE OPTIONS ➔ NUMBER DESCRIPTION	OPTION 1 ELECT. POWER LOAD MGT	OPTION 2 MATERIALS TRANSFER MGT	OPTION 3 INTERSUBSYS FAILURE ISOLATION	OPTION 4 INTERSUBSYS REDUNDANT PATH SEL.	OPTION 5 MAINTENANCE SCHEDULE MGT	OPTION 6 STARTUP INTEGRATION
FREQUENCY OF USE	OFTEN TO CONTINUOUS BECAUSE SPACE STATION GROWS AND EXPERIMENTS CHANGE SO POWER UNBALANCES WILL POP UP FREQUENTLY. FAILURES ALSO CAUSE UNBALANCED POWER USE TO SUPPLY.	OFTEN TO CONTINUOUS BECAUSE OF SPACE STATION GROWTH AND EXPERIMENTAL CHANGES ALSO THIS FUNCTION IS AFFECTED BY LOCATIONAL CHANGES AROUND THE SPACE STATION OF CREW OR EXPERIMENTS.	BECAUSE THE OCCURRENCES OF FAILURES ARE SOMEWHAT UNPREDICTABLE, THIS FUNCTION NEEDS TO BE CONTINUOUSLY AVAILABLE BUT PERHAPS NOT ON LINE UNTIL THE SUBSYSTEM FAILURE IS INDICATED– OCCASIONAL USE– CONTINUOUSLY AVAILABLE	WOULD BE USED IN EARLY STATION AFTER OPTION 3 FUNCTION HAD BEEN USED. LATER THIS MIGHT BECOME AUTONOMOUS AND THEN IT WOULD BE ON LINE. CONTINUOUSLY AS WOULD OPTION 3.	OCCASIONAL TO OFTEN BECAUSE THE ADJUSTMENT OF MAINTENANCE SCHEDULE COULD BE PUT OFF UNTIL A QUIET PERIOD EXISTED FOR THE COMPUTER.	THIS FUNCTION WOULD BE CALLED UP MUCH AS THE OPTION 3 AND OPTION 4 FUNCTIONS WOULD BE CALLED UP. THIS FUNCTION, HOWEVER, WOULD NOT BE A LIKELY CANDIDATE FOR AUTOMATION– OCCASIONAL.
RANKING	1	1	2	2	4	3
AUTONOMOUS PROCESSING	ASTRONAUTS WOULD PROBABLY LIKE THIS TO BE AUTONOMOUS	THIS WOULD ALSO BE A GOOD CANDIDATE FOR AUTONOMOUS IMPLEMENTATION	EARLY ON THIS WOULD BE INTERACTIVE. ASTRONAUTS WOULD PROBABLY LIKE TO BE ADVISED AFTER THE FACT	AGAIN ASTRONAUTS WOULD PROBABLY PREFER THAT THIS EVENTUALLY BE AUTOMATIC WITH AN ADVISORY OUTPUT.	ASTRONAUTS WILL WANT THIS TO BE INTERACTIVE.	THIS WILL BE INTERACTIVE AND ASTRONAUTS PROBABLY WILL AGREE.
RANKING	1	1	2	2	4	3
ESSENTIAL FOR SAFETY	THIS FUNCTION HAS A SECONDARY RELATIONSHIP TO SAFETY	SOMEWHAT RELATED TO SAFETY	THIS FUNCTION IS ABSOLUTELY NEEDED FOR A COMPLEXED AUTOMATED SET OF SUBSYSTEMS	THIS FUNCTION IS ALMOST AS ESSENTIAL AS OPTION 3.	NOT PARTICULARLY RELATED TO SAFETY.	SOMEWHAT RELATED TO SAFETY.
RANKING	2	2	1	1	5	4
DETERMINISTIC PROCESSING	HAS A RELIANCE ON KNOW-HOW AT LEAST FOR EARLY SPACE STATION	SOMEWHAT MORE DETERMINISTIC THAN OPT 1	LARGELY KNOW-HOW BASED AT FIRST–MAY BECOME DETERMINISTIC WITH EXPERIENCE SAME AS OPTION 1	ABOUT THE SAME AS OPTION 3	THIS ONE WILL BE JUDGMENTAL BUT WILL ALLOW FOR MORE DATA COLLECTION BECAUSE TIME FOR DECISIONS IS GREAT	THIS ONE SHOULD BECOME DETERMINISTIC RATHER RAPIDLY BUT USE WILL DROP OFF TOO.
RANKING	2	3	2	2	4	4
DURABILITY	PROBABLY WILL TAKE A LONG TIME BEFORE THIS FUNCTION WILL GO AWAY–BECAUSE OF THE CHANGING STATION	LIKE 1 EXCEPT THAT TIME FOR DECISIONS IS GREATER SO MORE DATA CAN BE GATHERED	WILL GO AWAY SOONER THAN 1 BECAUSE EFFORT WILL ALWAYS BE GREAT TO ELIMINATE CRITICAL FAILURE MODES.	SOMEWHAT LESS DURABLE THAN 3	PROBABLY WILL BE AROUND AS LONG AS SPACE STATION IS EVOLVING	THIS ONE SHOULD GO AWAY FAIRLY RAPIDLY ONCE THE SPACE STATION SETTLES DOWN A LITTLE
RANKING	1	2	3	4	3	3
	7	9	10	11		

Figure 2.5-10 Trade of Integrating Controller Functions

These comparisons indicate that the start-up integration and maintenance schedule management are of lower priority than the other four functions. This seems somewhat reasonable because the space station would need the first four for smooth and safe operation, while the last two would be more like convenience functions.

In general, trade on architecture favor a distributed system where the requirements for computing capacity indicated by the function do not dictate extremely large units, which would be practical to duplicate on board the space station.

The comparison of a fully automatic system versus one where the astronauts interact thru a computer terminal involves human preferences. In many cases the astronauts would prefer not to be bothered with routine diagnosis and corrective action but in others such as scheduling and logistics the astronauts would want to maintain control. In a few cases such as attitude control or some power control the diagnosis and corrective action could require faster response than that which is consistent with human capability and that would favor the fully automatic approach. Finally, the acquisition of a knowledge base to develop the integrating controller system will benefit by the interactive experience of astronauts during the early missions. All of this indicates that the early space station will be characterized by a great emphasis on interactive controllers but as the station matures many functions will become fully automatic.

2.5.4 Cost and Benefits Analysis

Based on the integrating controller characterization developed in this study and the trade study considerations identified above, an update of the cost and benefits for advancing the expert systems technology can be established. In section 4.1.8 of volume II of the Advanced Platform Systems Technology Study Final Report, a cost and benefits estimate was made for the expert systems technology for an integrating controller. In the current study, we have developed a more detailed description of the functions of the controller and have focused on the programmatic trades with respect to those functions and that allows a more realistic estimate of costs and benefits.

The following assumptions are established for the cost update of this current study.

1. Six expert system functional elements plus one expert system selection element will be considered.

2. Each element is equivalent to one R1 expert system program (850 rules) except the intersubsystem failure isolation element, which is assumed to be 2,000 rules (see section 5.3.6). This gives a total of 7,100 rules for the integrating controller expert systems.
3. Based on the productivity reported in section 5.3.6, each rule requires 2 days of labor to develop. This is better than the productivity rate of 5 labor days per rule used in the previous study. We will assume the more conservative 5 days per rule rate.
4. Assume a labor rate of $400.00 per-man day for expert systems software development (this is nearly double the rate assumed for the last study).
5. Assume $1M for verification of each element for a total of $7M.
6. Based on the estimate of one general processor for each online function plus one for the expert system selector, we can estimate that at least three onboard general processors would be needed to implement the system. Assuming $1M for each we have $3M for additional hardware.

Based on the above assumptions a cost figure for the expert systems development and implementation is $24.2M. This includes approximately $12M for establishing flight resident software and for a set of flight computers.

For the benefits estimate we will consider a phased introduction of the integrating controller expert systems. This means that the yearly savings assumed in the previous study would be reduced.

The following assumptions apply to the benefits estimates for this study.

1. The labor to monitor the space station systems would be phased out as the integrating controller is phased in as follows:
    a. For year 1: six ground-based mission controllers plus ½ time astronaut (full coverage)
    b. For year 2 thru 5: one ground-based mission controller plus ½ time astronaut. (Reduction of five ground-base mission controllers for 4 years.)
    c. For year 6 thru 10: 1/10 time ground-based mission controller plus 1/10 time astronaut. (Reduction of 5.9 mission controllers and 0.4 astronaut for 5 years).

2. Mission controller labor rate is $1500 per 24-hour day or $550,000 per year for each controller
3. Astronaut labor rate is $77,000 per 24-hour day or $28,200,000 per year.
4. Resupply and maintenance cost savings due to the integrating controller are estimated as $25M over a 10-year mission due to more efficient use of resources onboard and more managed maintenance operations.
5. Half of the above benefits of an integrating controller can be attributed to use of expert systems.

Based on the above assumption the benefits of the expert systems part of an integrating controller are estimated at $54.0M.

The resulting cost to benefits ratio then is 0.44. This is a significant movement from the 0.098 ratio estimate of the previous report but still leaves the expert system development with all the associated unquantified benefits as an attractive technology for advancement.

2.5.5 Conclusions

The conclusion from this study are:

1. The integrating controller has real and useful functions on a space station.
2. The implementation of the controller would profit from expert systems programming.
3. The implementation will be phased and updated during the early years of the space station operations.
4. The costs are high but so are the benefits.
5. This technology advancement is essential if the space station autonomy/automation philosophy is to be implemented.

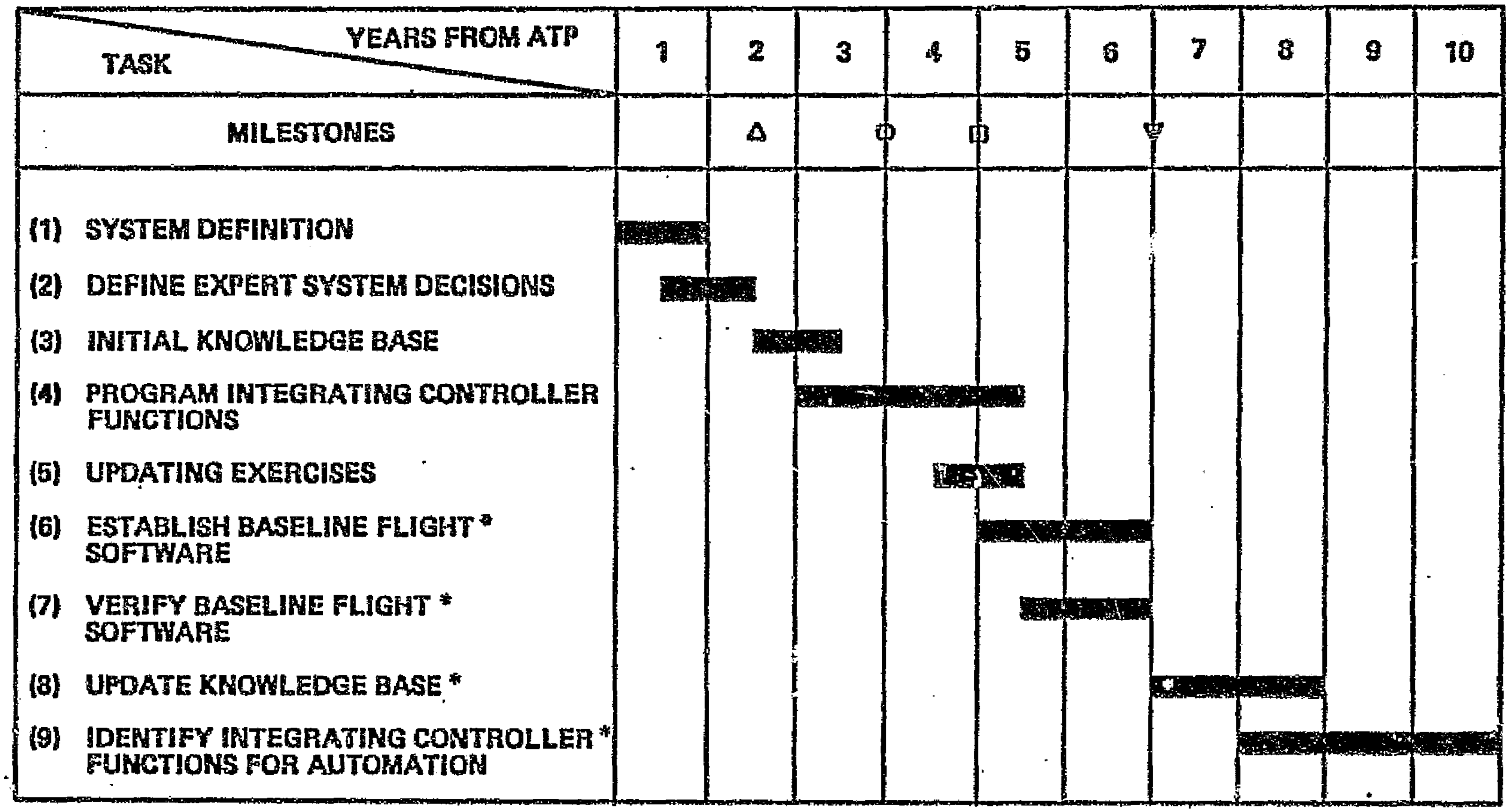
2.5.6 Technology Advancement Plans

The integration of automated control systems for space station housekeeping subsystems, such as the electrical power subsystem, life support, and thermal control, would provide cost savings as well as safety, efficiency, and maintainability benefits to space station design and operation.

Table 2.5-6. FY84, RTOP Submissions Related to Technology Applicable to The Space Station Integration of Automated Housekeeping System Advancement

Center	Title	Objectives	Benefits
Ames Research Center	Advanced Concepts for Knowledge-Based Expert Systems	o Development of basic computer science tools required for knowledge-based expert systems. Will provide the impetus for automated spacecraft, space platforms, scientific instruments, and ground based stations.	o Use of these tools in automated expert systems will result in more scientific return per unit dollar and minimum labor-intensive tasks.
Langley Research Center	Automation Systems Research	o Develop and support the technology base required to design, develop, and automate teleoperator and robotic systems.	o Enhance man's capabilities for future space activities including servicing, maintenance and repairing, structural assembly, and space manufacturing.
Lyndon B. Johnson Space Center	Automations Technology for Manned Space Systems	o Develop automation technology as applied to manned space transportation and space station systems.	o Certain systems, when the present level of technology and existing manned transportation complexity as extrapolated from systems to those of the future and that required by the space station, will be entirely impractical unless it is automated.
Jet Propulsion Laboratory	Autonomous Spacecraft Systems Technology Program	o To develop expert systems for a manned space station	o Autonomous operations will have several benefits including reducing the on-orbit work load of the space station crew. and reducing the number of ground support personnel and resources required to support SS dedication.

A survey of related RTOP's for FY 84 (table 2.5-6) indicates that the technology base is being developed in this area but that base should be expanded to meet the needs identified by this study. While the specific goals of this plan are unique, the integration of automated housekeeping functions impacts not only the subsystems mentioned but the data management area as well. The architecture of space station data management must support the design requirements imposed by these developments. The plan for the technology advancement associated with integration of automated housekeeping is presented by the schedule and resource information of figure 2.5-11 and table 2.5-7, respectively.



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*SCHEDULED TASKS RELATE FLIGHT SYSTEM DEVELOPMENT AND UPDATING

Figure 2.5-11 Schedule for Integrating Controller Technology Advancement Program

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Table 2.5-7 Resources for Integrating Controller Technology Advancement Program

TASK \ YEARS FROM ATP	1	2	3	4	5	6	7	8	9	10	TOTAL
FIGURES IN $1000 (1983)											
(1) SYSTEM DEFINITION	200										200
(2) DEFINE EXPERT SYSTEM DECISIONS	100	100									200
(3) INITIAL KNOWLEDGE BASE		300	200								500
(4) PROGRAM INTEGRATING CONTROLLER FUNCTIONS			500	1000	1500						3000
(5) UPDATING EXERCISES				500	500						1000
(6) ESTABLISH BASELINE * SOFTWARE					2000	4800					6800
(7) VERIFY BASELINE FLIGHT* SOFTWARE					2000	4000					6000
(8) UPDATE KNOWLEDGE BASE*							500	500			1000
(9) IDENTIFY INTEGRATING * CONTROLLER FUNCTIONS FOR AUTOMATION								500	1000	1000	2500
TOTAL	300	400	700	1500	6000	8800	500	1000	1000	1000	21200

*RESOURCES USED FOR FLIGHT SYSTEM DEVELOPMENT AND UPDATING